THE TROPOPAUSE DURING A MAJOR CHANGE IN CIRCULATION OVER THE WESTERN UNITED STATES, NOVEMBER 25 TO 28, 1954

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INTRODUCTION

Due to the growing interest in the tropopause chart, it is felt that a detailed study of tropopause behavior during an outstanding synoptic situation would be an interesting contribution. During the latter part of November 1954 there were rapid changes in the long wave pattern over the Western Hemisphere. A feature of particular interest noted during this period was the rapid (3-day) replacement of the long wave ridge aloft over western North America by a trough. At the surface, a warm High over the West was replaced by moving Lows and cold Highs with frontal systems migrating southward to the Mexican border which resulted in colder weather throughout the West. This paper emphasizes changes in the tropopause during this period with secondary emphasis on the relationship of the tropopause to other upper air features and to surface conditions.

DEFINITION AND DISCUSSION OF TROPOPAUSE

Due to numerous flights into the stratosphere during the last decade, and to the more dense radiosonde and rawinsonde networks, there has been an opportunity for a more detailed analysis of that zone between the troposphere and the stratosphere. This zone or boundary is commonly called the tropopause. In the troposphere the temperature generally decreases with height, while in the lower stratosphere it is quite often constant or increases with height. Frequently the change from tropospheric lapse rate to stratospheric lapse rate is so gradual that it is impossible to determine the point of stabilization. In order to keep the analyses of the tropopause charts as objective as possible, WBAN Analysis Center has adopted the definition of the tropopause point agreed upon by the World Meteorological Organization [1]. The predominant tropopause is found at the lowest point in the sounding where the lapse rate decreases to 2° C. or less per kilometer and averages 2° C. or less per kilometer for the first 2 kilometers above the point of stabilization. Frequently several such stabilization points are found on a sounding, in which case the lower point is considered the predominant tropopause. Points which do not meet the definition of a tropopause, but show stabilization as well as satisfying the requirement that the lapse rate be 3° C. per kilometer less than the layer immediately below are called significant points. Strict compliance to these definitions is not always practical and deviations for the sake of continuity are often necessary.

The potential temperature along a tropopause surface is conservative with respect to time, and generally conservative (15°–20° C.) with respect to space. Many authors have typed or named tropopauses with respect to their potential temperatures. Such titles as Arctic, polar, extratropical, and tropical have been suggested. The tropical tropopause with a potential temperature near 400° A. seems to be the only one for which there is uniform agreement.

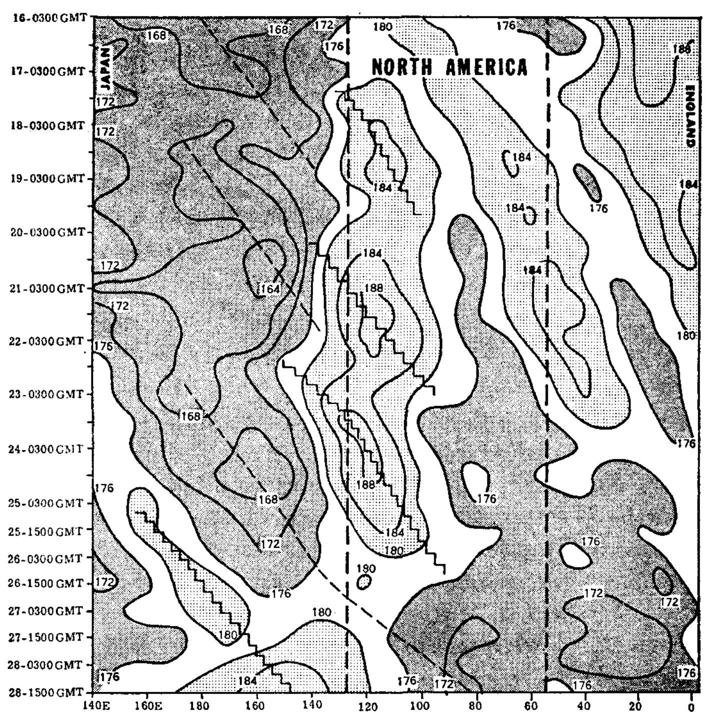

FIGURE 1.—500-mb. time cross section [3] at 50° N. latitude for November 16–28, 1954. Contours in hundreds of feet. The two heavy dashed vertical lines represent the coast lines of North America at 50° N. latitude, the left border Japan, and the right border England. Heavy shading indicates areas of low heights and dashed lines indicate movement of minor troughs. Light shading indicates areas of high heights and zig-zag lines the movement of minor ridges. Note rather stationary major ridge over western North America until the 26th with minor ridges moving from the Pacific and reaching maximum intensity in this favorable area. A good Pacific trough moved across the west coast on the 27th and in the Eastern Pacific a major ridge replaced a trough that had been in that position for 30 days (only 7 of these days show on chart).

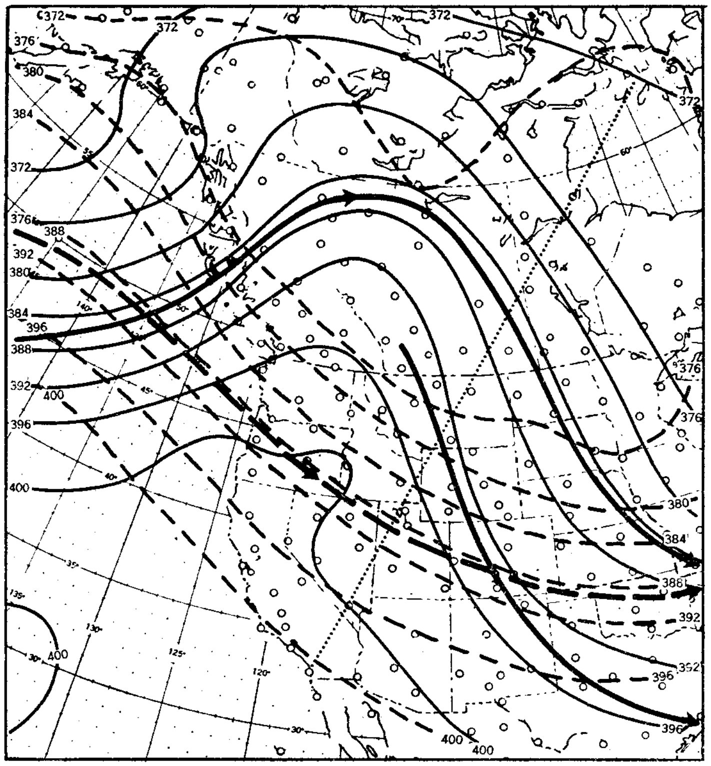

FIGURE 2.—200-mb. contours in hundreds of feet and jet streams (heavy lines), for 0300 GMT, November 25 (solid) and 0300 GMT, November 28, 1954 (dashed). Dotted line represents position of cross sections.

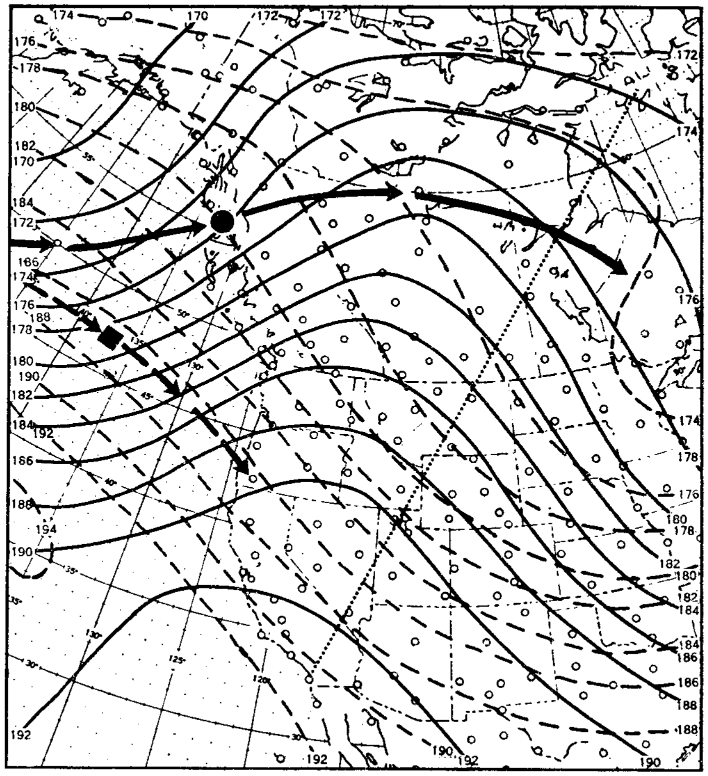

FIGURE 3.—500-mb. space mean contours [5, 6] in hundreds of feet and trajectory of relative cyclonic vorticity centers (heavy arrows). Solid lines, both contours and trajectories, for 0300 GMT November 25 and dashed lines for 0300 GMT, November 28, 1954. The dot and square are positions of a cyclonic vorticity center at map time while arrow heads show past and succeeding 12-hour positions.

The generally accepted explanation of the difference in lapse rates between the troposphere and stratosphere is that the troposphere is a region in which the turbulent transfer of heat upward is dominant, while the stratosphere is a region of radiative balance [2]. There are many other hypotheses concerning the theoretical explanation of the tropopause; however, we will not attempt further discussion on this controversial subject.

A CHANGE IN CIRCULATION

During the middle of October a mean ridge existed over the central United States with a trough along the west coast. On October 23 the ridge retrograded to a position over the Western States, while the trough moved westward into the Pacific Ocean. For the next 30 days, the ridge and the trough remained practically stationary. The latter part of this stationary period is shown on the 500-mb. time cross section [3] as the relatively high heights over the Western States (fig. 1). Of course, minor troughs moved regularly through the mean ridge position, but weakened perceptibly while doing so.

From November 23 to 28, there occurred a very rapid retrogression of the western ridge. During this interval the mean ridge actually replaced the mean trough that had previously existed over the Pacific. The events that led to this major change were the successive intensification and weakening of the rapidly moving minor troughs and ridges. First, the ridge over the West moved eastward and weakened. Simultaneously, a trough from the Pacific moved across the west coast with considerably more intensity than any during the previous 30-day period. This trough intensified and reached a maximum depth over the central United States. Previous troughs had reached their maximum intensity over the east coast. The first step in the retrogression process was the rapid intensification of a minor Pacific ridge reaching its maximum intensity in the eastern Pacific. Thus, during this brief period, the Pacific trough was replaced by a ridge, and the ridge over the western United States was replaced by cyclonic flow (figs. 2 and 3). For a more complete study of the major circulation see preceding article by Hawkins [4].

CHANGES IN THE TROPOPAUSE

Vertical cross sections are the most convenient tool in a tropopause analysis. For convenience in cross section analysis it is important that the wind field be perpendicular to the cross section in order to avoid the task of computing perpendicular components of these vectors. A selected cross section from San Diego, Calif. to Churchill, Manitoba, Canada, met this requirement very well. Figures 2 and 3 indicate how the flow changed from anticyclonic to cyclonic but remained essentially perpendicular to this cross section.

At 0300 GMT November 25, a warm ridge aloft (figs.

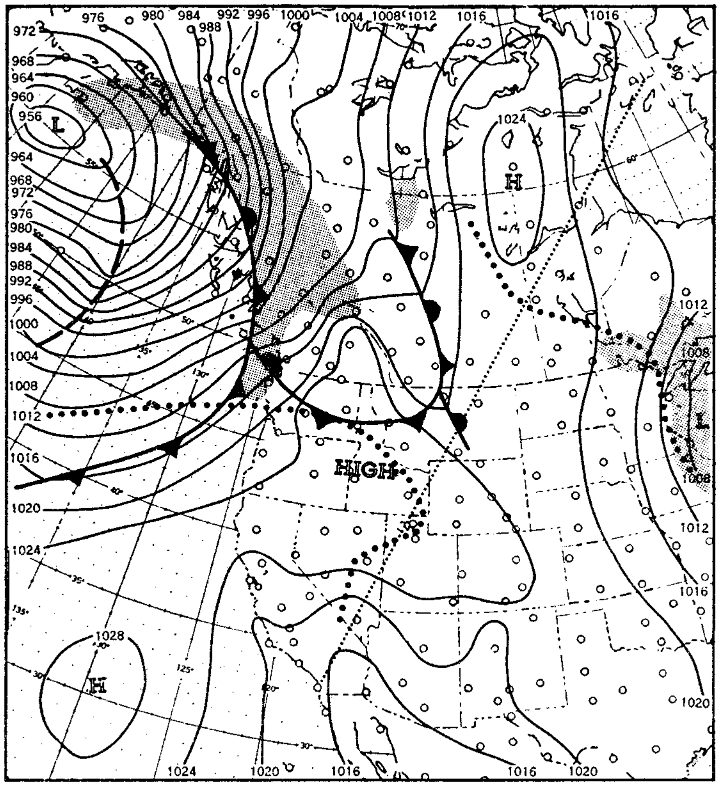

FIGURE 4.—Surface chart for 0030 GMT and tropopause break line (dotted) for 0300 GMT, November 25, 1954. Shading indicates areas of active precipitation.

2 and 3) covered western North America. At the surface (fig. 4) pressures were also high with a warm cell over the Plateau, a cool maritime Pacific ridge over southwestern Canada and a polar High over central Canada. A dissipating warm type occlusion separated the mP ridge from the cP High. The remains of the upper cold front associated with the dissipating occlusion appeared on the cross section over Glasgow, Mont. (fig. 5). The Arctic tropopause with a potential temperature from 310° to 325° A. existed near 300 mb. and extended as far south as The Pas, Manitoba, Canada, where its relationship with the upper front became diffuse. Above the southern edge of the Arctic tropopause there was a weak jet core. This jet corresponds to the tropopause break-line in figure 4. Just above the jet core near 200 mb. were found the first of two polar tropopause leaves (fig. 5). The lower polar leaf with a potential temperature near 335° A. appeared to lie directly through a strong jet core over Great Falls, Mont., and extended southward to Salt Lake City, Utah, where there was another tropopause break-line (fig. 4). The upper polar leaf near 150 mb. with a potential temperature of 344° to 370° A. extended southward to off the California coast and showed considerable overlap (fig. 5). The tropical tropopause near 100 mb. with a potential temperature of about 400° A. extended from Great Falls southward. The cross section does not extend far enough south to show the southern limits of the upper polar leaf. Continuity from previous upper air charts indicates that there was a high level jet over Baja California at the supposed break-line between the polar and tropical tropopauses.

The cross section for 1500 GMT, November 25 (fig. 6) shows the remains of the quasi-stationary front reaching the ground near Havre, Mont. This front, located in the lee-of-the-mountains trough, also shows up on figure 5. The upper cold front that was approaching Great Falls moved eastward out of the cross section; however the frontal zone still existed aloft over Canada. An approaching minor upper level trough caused the upper level winds over Canada to shift from northwest to west. At the same time, the minor jet in the vicinity of The Pas, the northern edge of the polar tropopause, and the southern limit of the Arctic tropopause all moved northward. The northern limits of the upper polar and tropical tropopauses also moved northward. The main jet located over Montana moved slightly southward. The polar leaf still appeared to lie through the jet core and extended rather weakly all the way to California.

By 0030 GMT on the 26th (fig. 12) a new surge of mP air moved into the northern Rockies accompanied by a deepening minor trough aloft. Figure 7 shows the deepening cold air from Ely, Nev., to Glasgow and the warm type occlusion over The Pas. An old upper cold front lay parallel to and east of the cross section over the Northern Plains (not shown on surface chart.) Over Coral Harbour, District of Keewatin, Canada (915) the remains of the Arctic tropopause could barely be found. However, there was a well-defined polar tropopause point at 300 mb. A remarkable feature on this cross section is that the strong upper polar leaf previously found at 150 mb. (fig. 6) was now very weak while the tropical tropopause had strengthened and extended much farther north. These changes appear to have been a part of the large scale process whereby old polar-Low stratospheric air at high levels over the Southwest was assuming the characteristics of tropical air through modification and advection.

The mP air deepened and continued to move eastward onto the Northern Plains by 1500 GMT of the 26th. The cross section for this time (fig. 8) shows the surface front was approaching Las Vegas, Nev. and the cold air had deepened to the top of the troposphere over Saskatchewan, Canada. The jet core continued to move southward and to a lower elevation. Following the deepening of the cold air over the northern Rockies, the jet strengthened considerably with maximum winds increasing in 12 hours from near 130 knots to 160 knots and simultaneously the lower polar tropopause appeared to break. The northern part of this leaf sloped to lower elevation to the south and merged with the lower boundary of the cold front. The southern half of the polar tropopause had intensified and extended to California.

By 0030 GMT, November 27 (fig. 13) an mP High had broken off from the Pacific High and was located over the

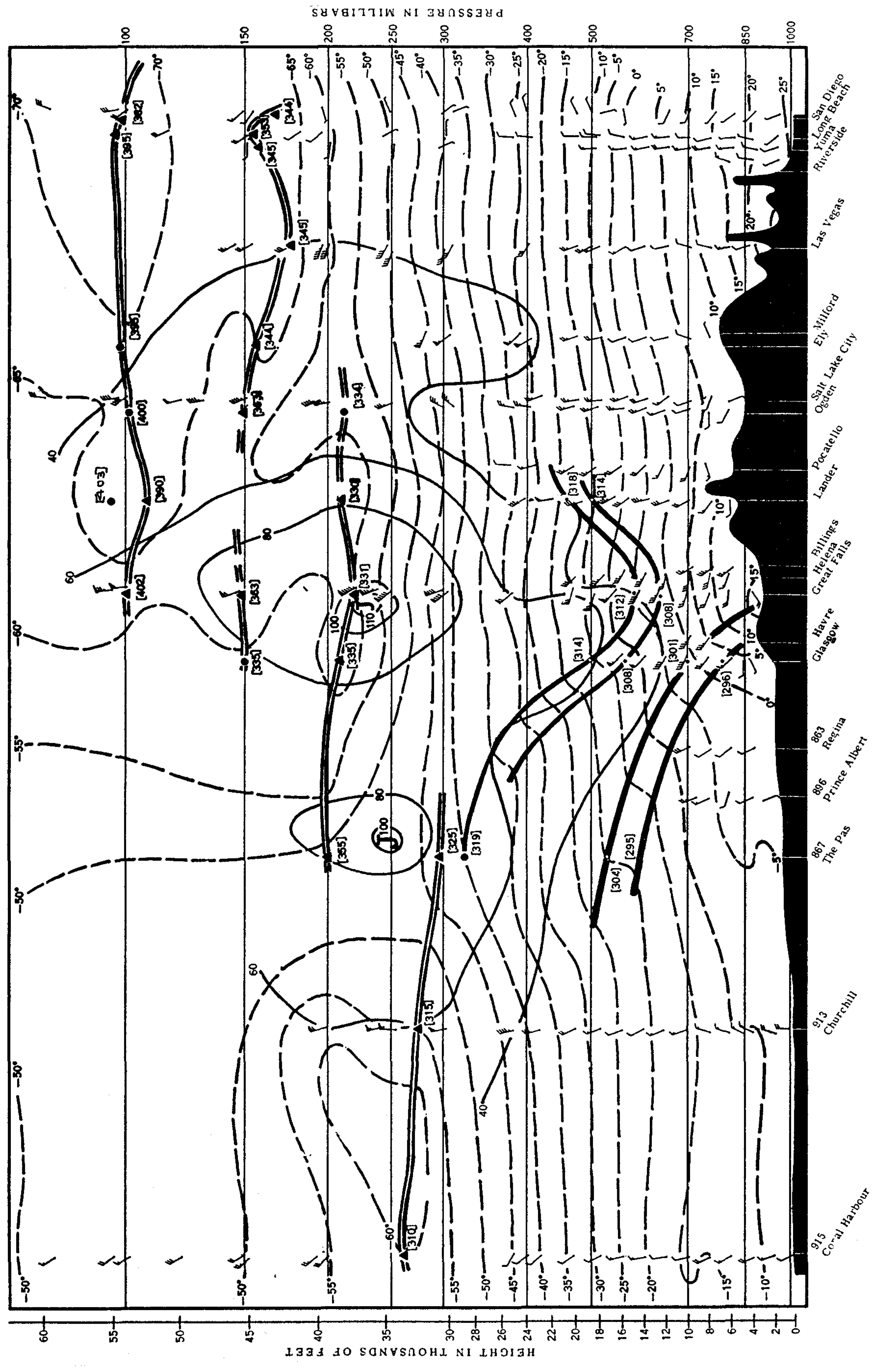

FIGURE 5.—Cross section at 0300 GMT, November 25, 1954. Heavy lines indicate fronts, dashed for weaker portions. Horizontal heavy line indicates tropopause, dashed in weaker portions. Isotherms in °C. are shown as dashed lines. Isotachs (thin solid lines) are in knots. Large "J" shows position of jet core. Large triangles are tropopause points while circles are significant stabilization points. Small dots represent minor stabilization and frontal points. Numbers in brackets are potential temperatures. Front reaching ground near Glasgow is quasi-stationary with cold front aloft approaching Great Falls from the north. Note that when projected to the cross section, Yuma happens to fall on the wrong side of the coastal mountains.

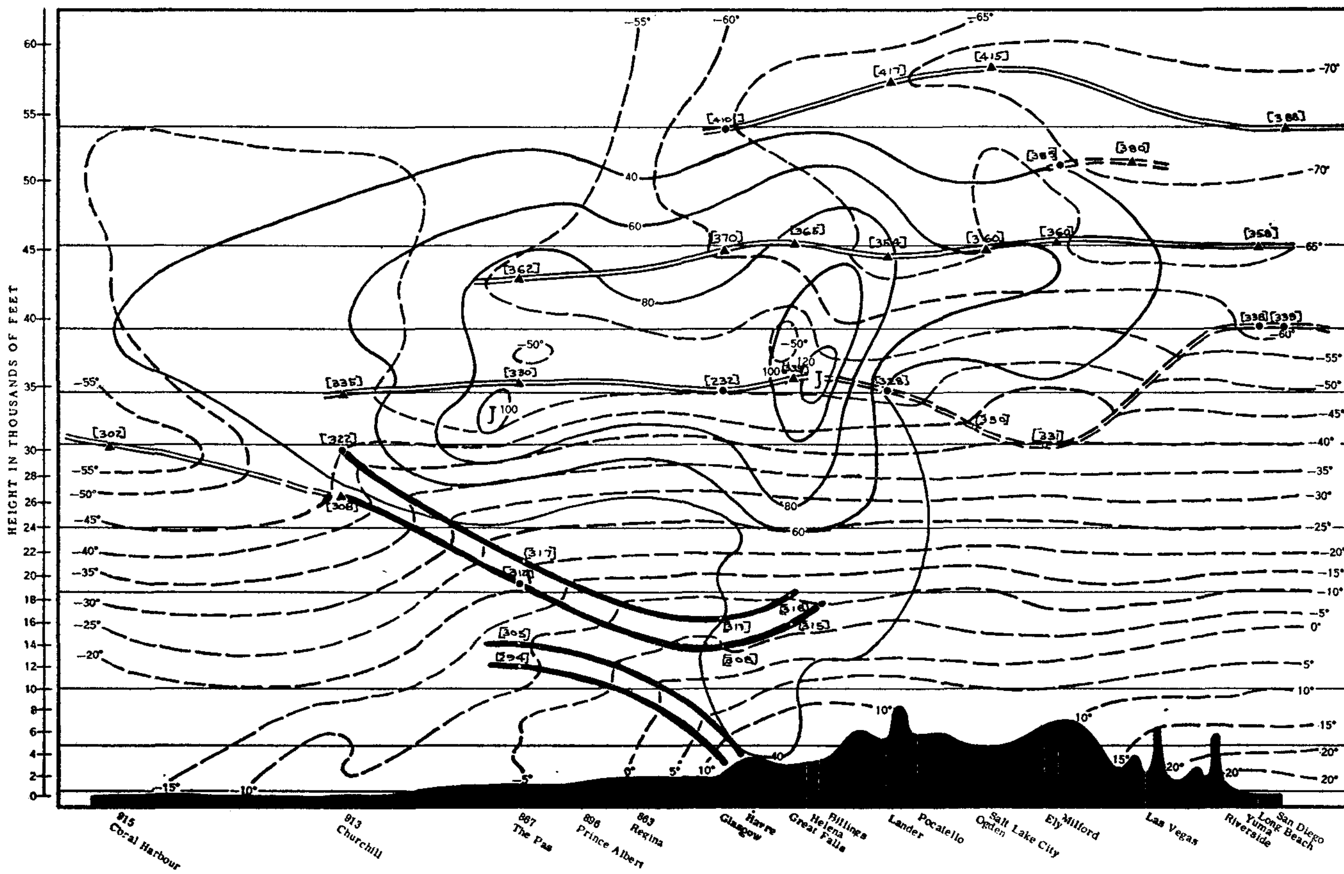

FIGURE 6.—Cross section at 1500 GMT, November 25, 1954. Warm front reaches ground near Glasgow. Upper front is remains of system to the east of cross section.

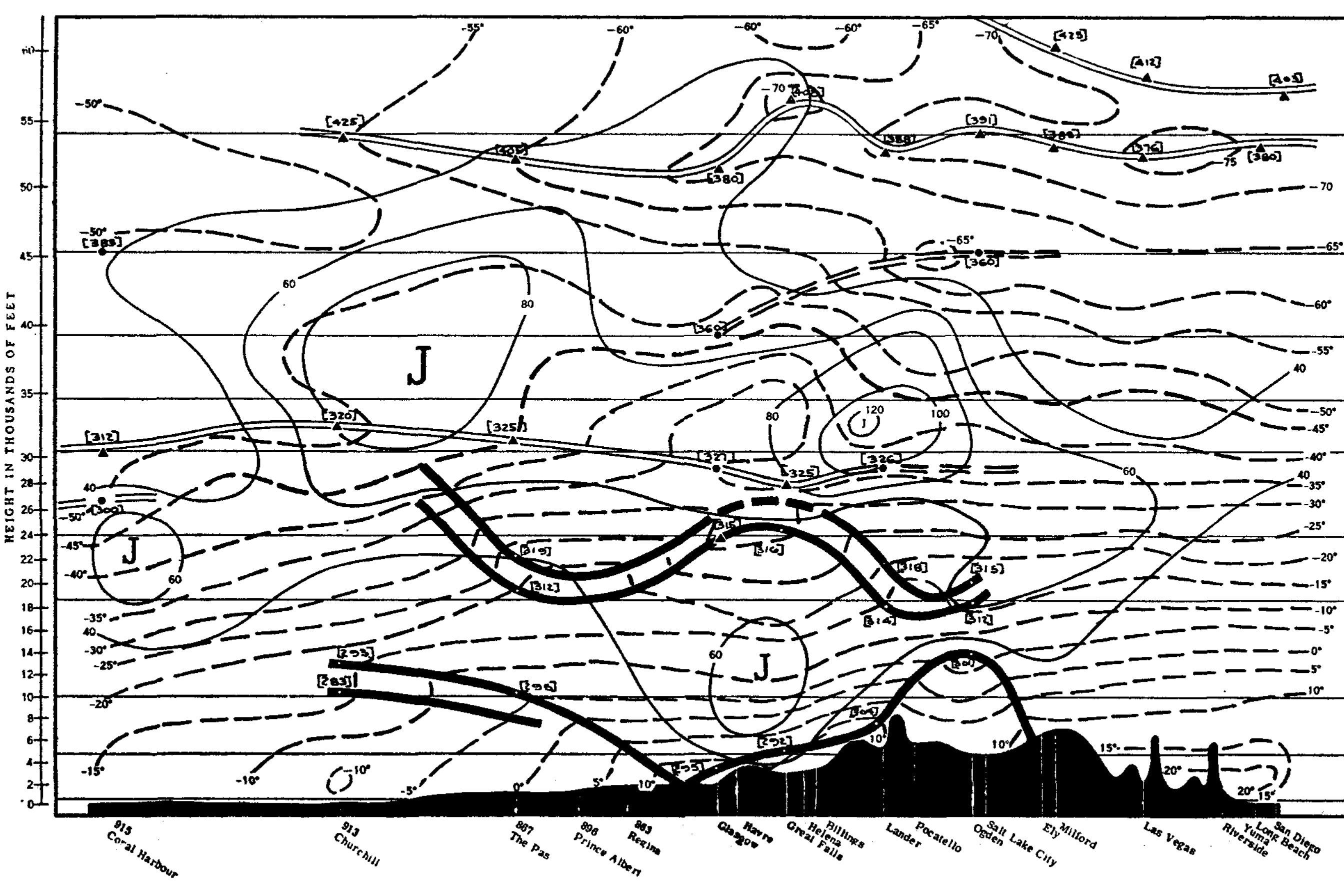

FIGURE 7.—Cross section at 0300 GMT, November 26, 1954. Cold dome from Ely to Glasgow with occlusion in Canada. Upper front is not associated with warm occlusion but is the remains of systems farther east. Note that the analysis neglects the 250-mb. wind at Great Falls. The angle of elevation was so small that the sounding was incomplete for the next 10,000 feet and since a high velocity would be completely incompatible with the thermal field disregard of the report is believed to be justified.

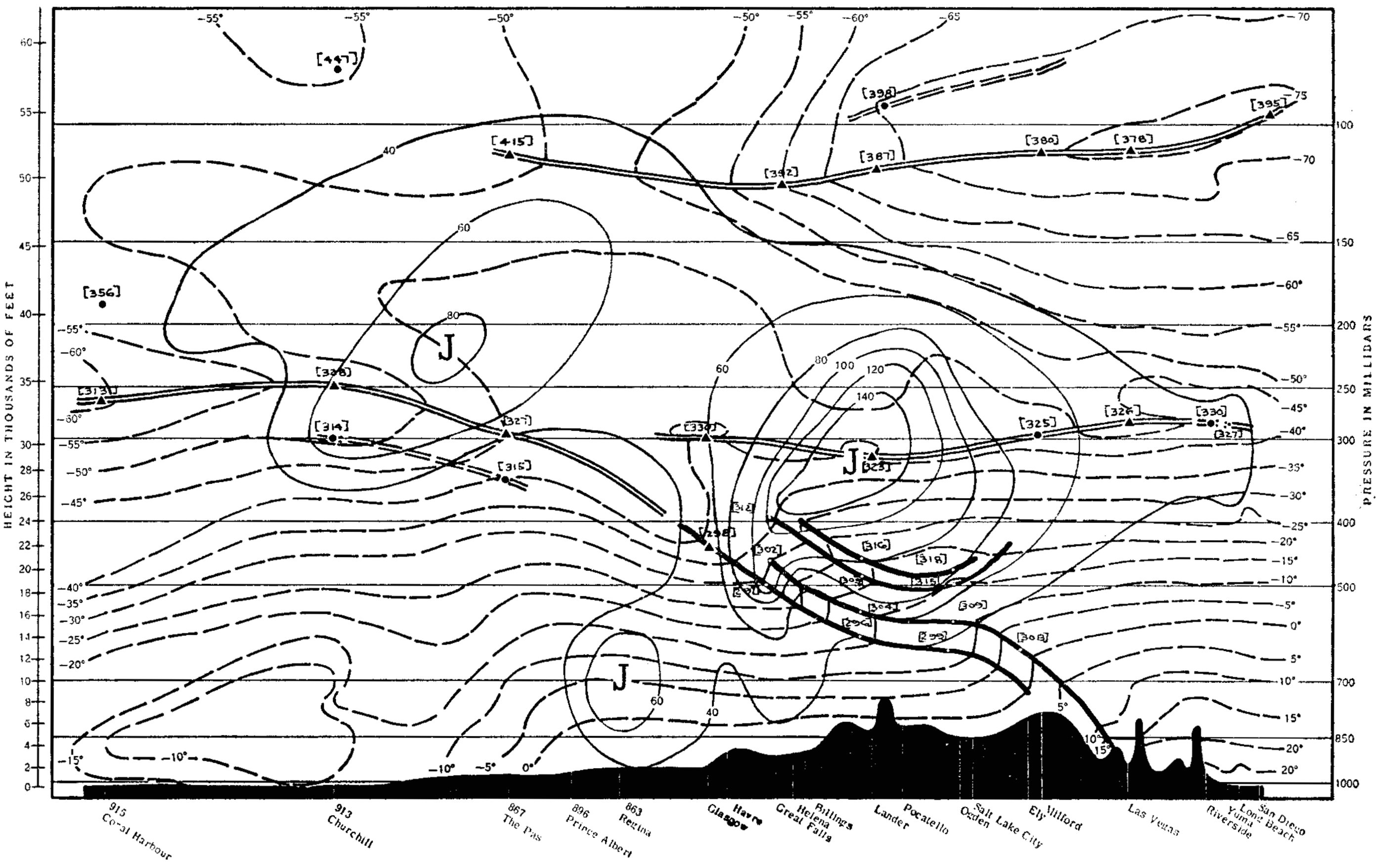

FIGURE 8.—Cross section at 1500 GMT, November 26, 1954. Note that cold air over Wyoming and Montana is now quite deep and polar tropopause is starting to split near the Canadian border. That portion of the polar tropopause from Lander to Glasgow lying through the jet core is untenable and disappears during the next 12 hours. An alternate analysis would be to join the tropopause at 300 mb. from The Pas to Glasgow and consider that a new lower tropopause is forming near the front.

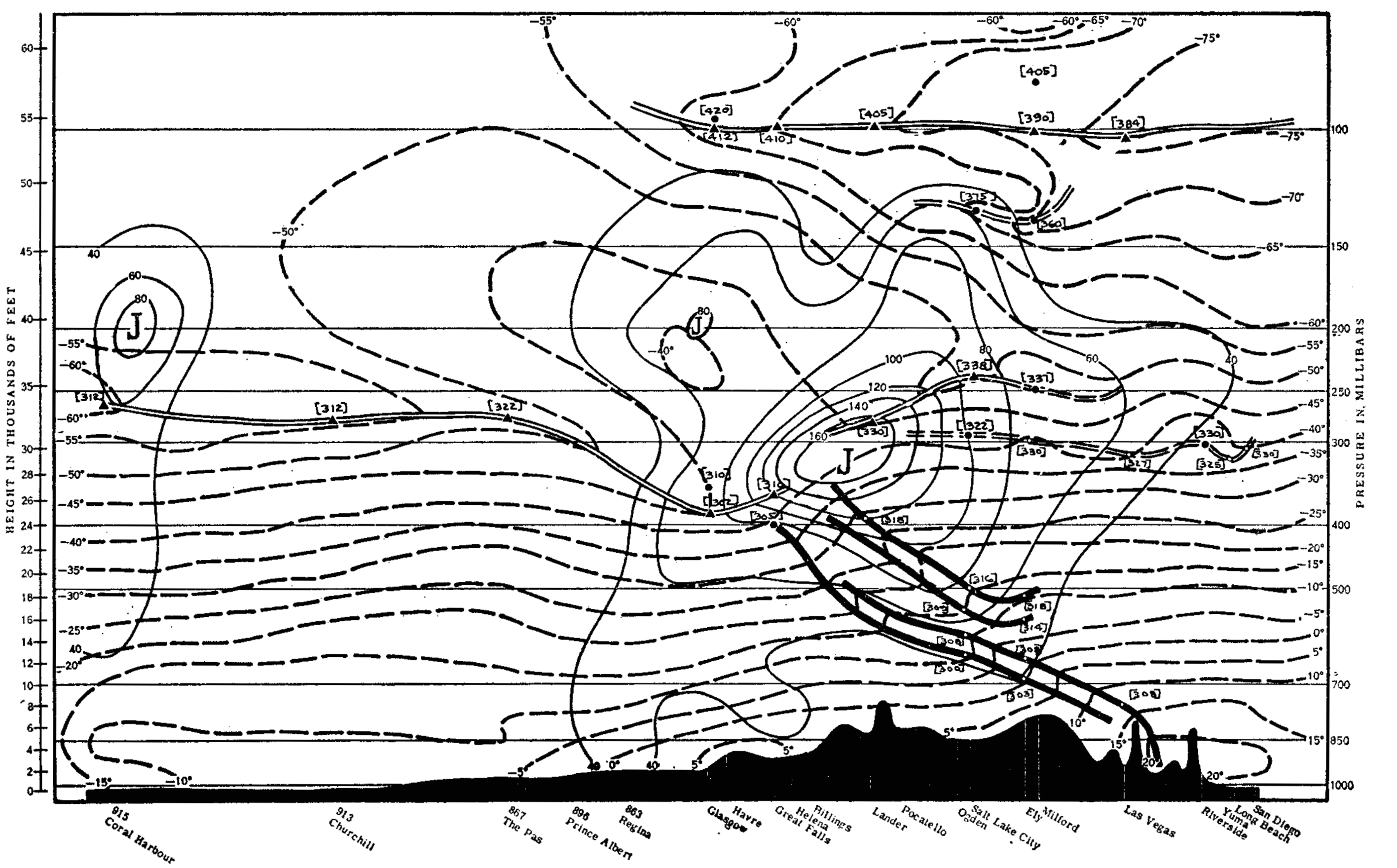

FIGURE 9.—Cross section at 0300 GMT, November 27, 1954. Now all of the troposphere north of the cold front has cooled and the fracture of the tropopause continues in the vicinity of the jet core. To the south of the jet core a new tropopause is forming near the 250-mb. level while the old one at 300 mb. weakens.

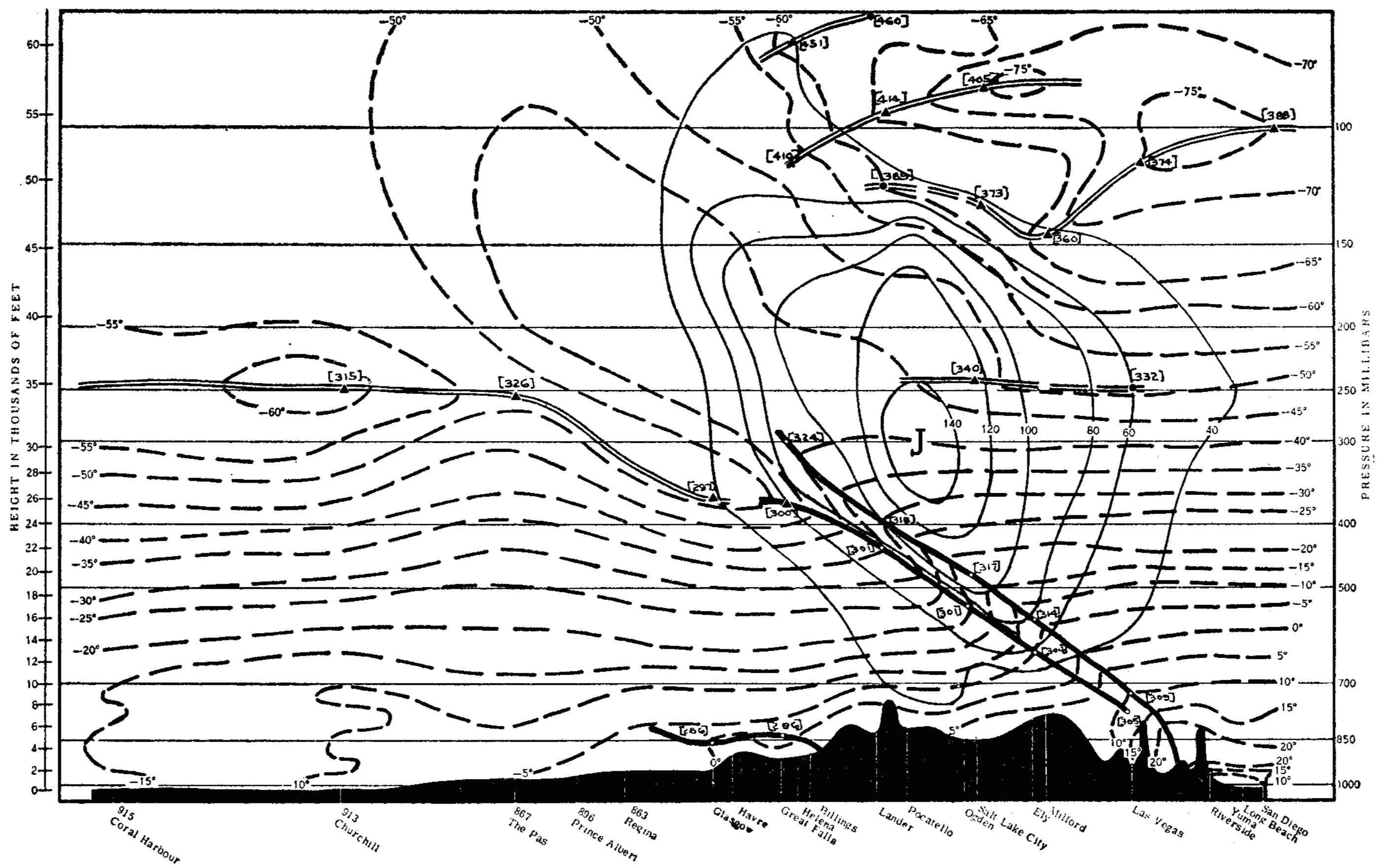

FIGURE 10.—Cross section at 1500 GMT, November 27, 1954. New fast moving occlusion just enters cross section near Great Falls. Old tropopause over the Southwest at 300 mb. has disappeared.

Plateau. The cold front continued to move slowly southward and there was still evidence of the double frontal zone over the northern Rockies (fig. 9). The jet continued to intensify with maximum winds then near 180 knots. It was then 12 hours after the fracturing of the tropopause that had lain through the intensifying jet. The southern part of this tropopause (at 300 mb.) had weakened considerably, while a new one formed just above it at 250 mb. The potential temperature of the new leaf was about 5° warmer than that of the weakening one. A study of the soundings indicates that these changes were neither dry nor moist adiabatic and thus were not a result of vertical motions and so must have been due mainly to advective processes since radiative modifying processes are at present considered to be too slow to give temperature changes of this magnitude in this small time interval.

By 1500 GMT on the 27th a new mP occlusion moved into the Northwest and just barely shows on the cross section (fig. 10) at Glasgow and Great Falls. The surface High over the Plateau weakened while the cold front in southern California became quasi-stationary. Aloft, the jet core continued its slow drift to the south and to lower elevations. The split in the Polar tropopause was now completed with the southerly leaf at 250 mb. well established while the old one, formerly at 300 mb., completely disappeared. For the first time in two days there seemed to be changes taking place in the tropical tropopause which had formerly maintained a horizontal position at 100 mb. However, it now broke into three leaves sloping downward to the north.

The surface occlusion moved rapidly southeastward and by 0030 GMT, November 28 (fig. 14) covered most of the Rockies and had practically caught up with the previous surface cold front. In fact, the occlusion and the old cold front appeared as one over southern California (fig. 11). The fresh cold air brought into the region had reintensified the jet so that winds of over 180 knots were probable in the core. Again the core had moved south and to a lower elevation. The polar tropopause to the north was unchanged but the southern leaf continued to rise. During the last 24 hours it had risen from 300 mb to near the 200–mb. level with its potential temperature warming about 10°. Actually the above process was the result of reformation at a higher level during the first 12 hours and apparent rising the next 12 hours.

A review of this analysis of tropopause behavior shows the following: At the start of the period, with warm ridge conditions aloft and a cP High at the surface, an Arctic tropopause existed over Canada; then as the ridge aloft weakened, mP air replaced cP air over Canada and the Arctic tropopause disappeared leaving only polar and tropical tropopauses; next, with continued weakening of the ridge aloft, mP air moved farther south in the Western States; and finally, when trough conditions aloft did exist

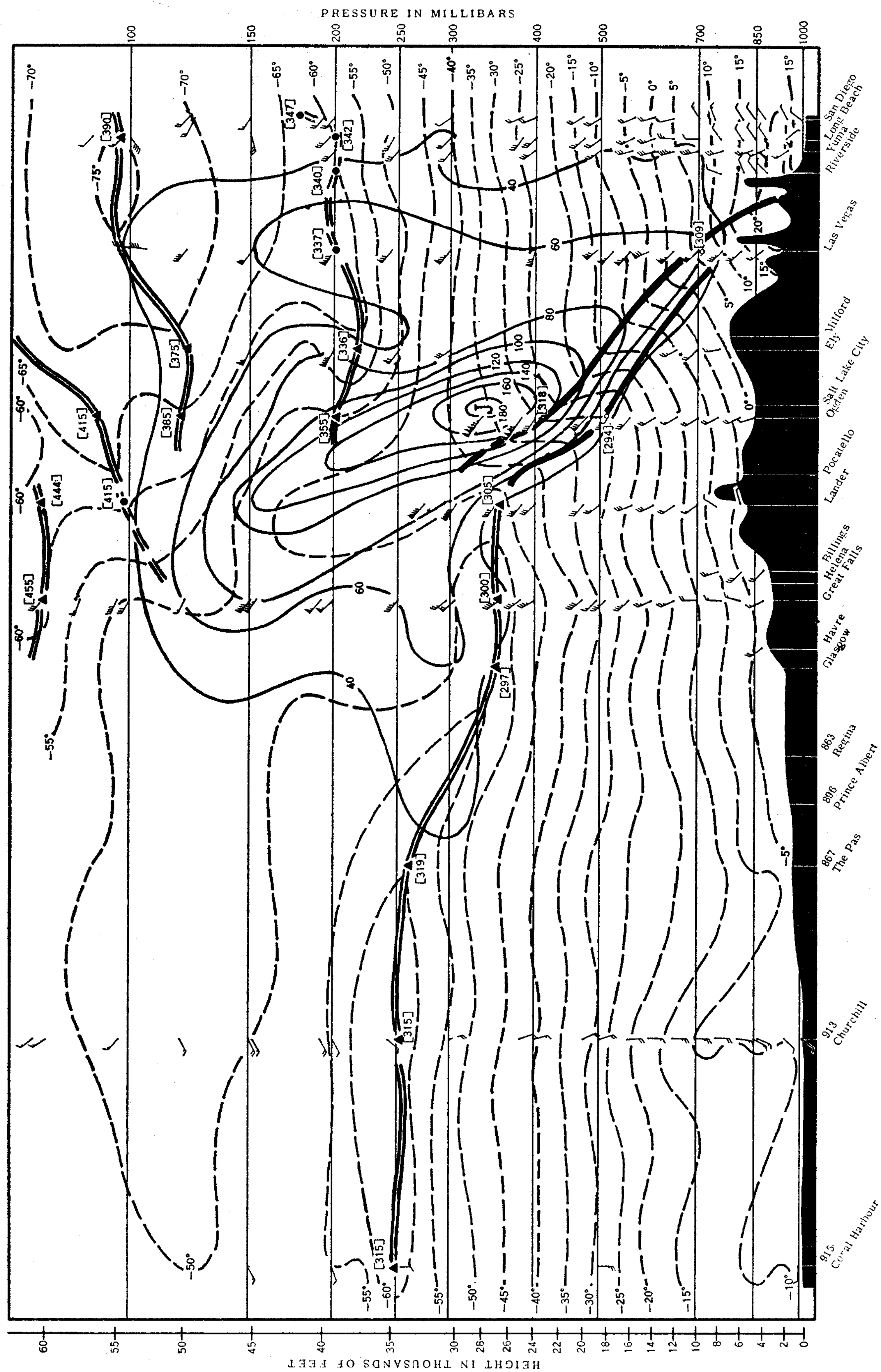

FIGURE 11.—Cross section at 0300 GMT, 82, November 1954.. During last 12 hours new occlusion has moved rapidly southward and reinforced and merged with cold front over California. Note that the polar tropopause over the Southwest continues to lift and is assuming tropical characteristics.

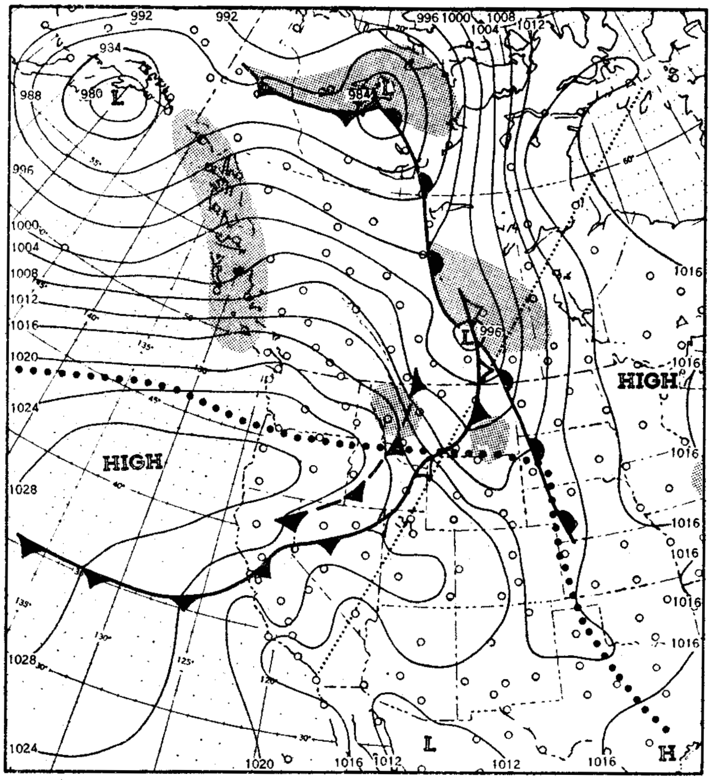

Figure 12.—Surface chart for 0030 GMT and tropopause break-line for 0300 GMT, November 26, 1954.

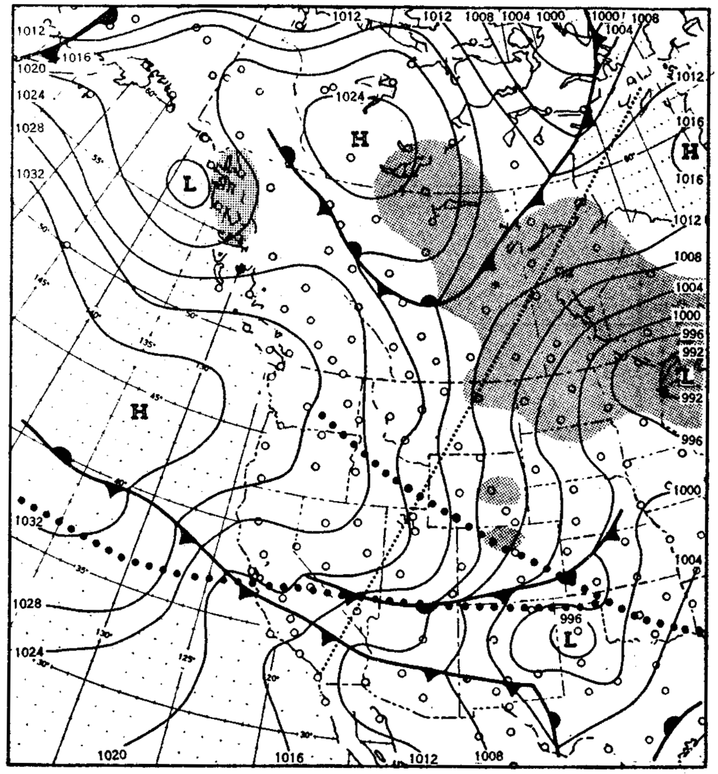

Figure 14.—Surface chart for 0030 GMT and tropopause break-line for 0300 GMT, November 28, 1954.

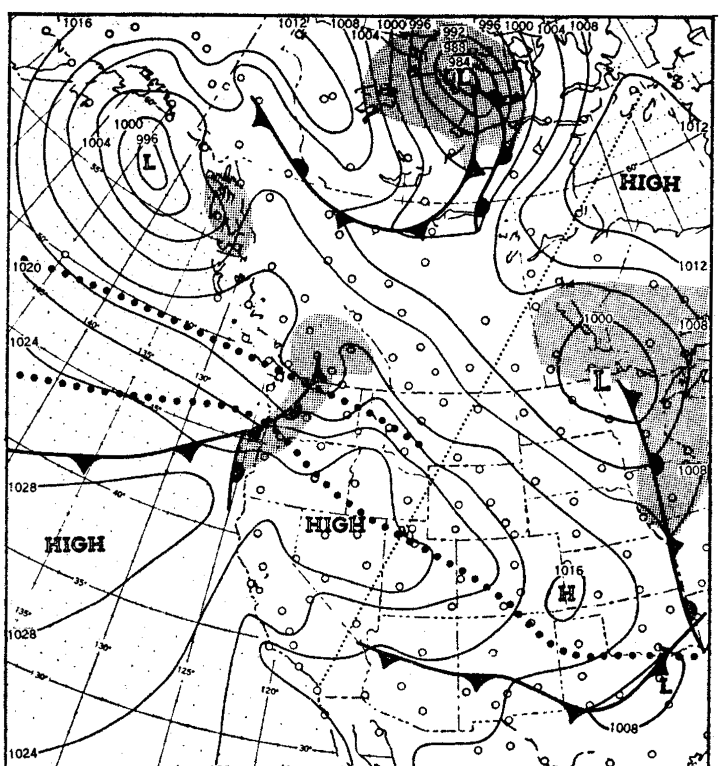

Figure 13.—Surface chart for 0030 GMT and tropopause break-line for 0300 GMT, November 27, 1954.

over the West, the mP air deepened throughout the troposphere, the jet stream associated with the mP air strengthened, and the polar tropopause split with its southern leaf gradually rising and taking on more tropical characteristics.

OTHER RELATIONSHIPS

In the WBAN Analysis Center relative vorticity at the 500-mb. level is computed graphically by the Fjørtoft technique [5,6]. In figure 3 the movement of cyclonic vorticity centers in relation to the mean flow is illustrated both for the beginning and ending of the 3-day interval. With the warm ridge over western North America the cyclonic vorticity moved east-northeastward into western Canada. At this time the Arctic tropopause was the dominant feature in Canada. By the 28th, with cyclonic flow over the West, the cyclonic relative vorticity centers (of moving systems but not of major troughs) were moving east-southeastward toward the Plateau region. At this time an intensifying jet was located near Salt Lake City and the polar tropopause had split.

The change in the position of the jet stream at the 200-mb. level can readily be seen from figure 2. This is representative of the approximate position of the jet stream at other levels, but the slope with altitude varies as shown in figure 15. Under warm-ridge conditions the vertical axis of the jet sloped to the south with altitude. With the breakdown of the warm ridge and the influx of

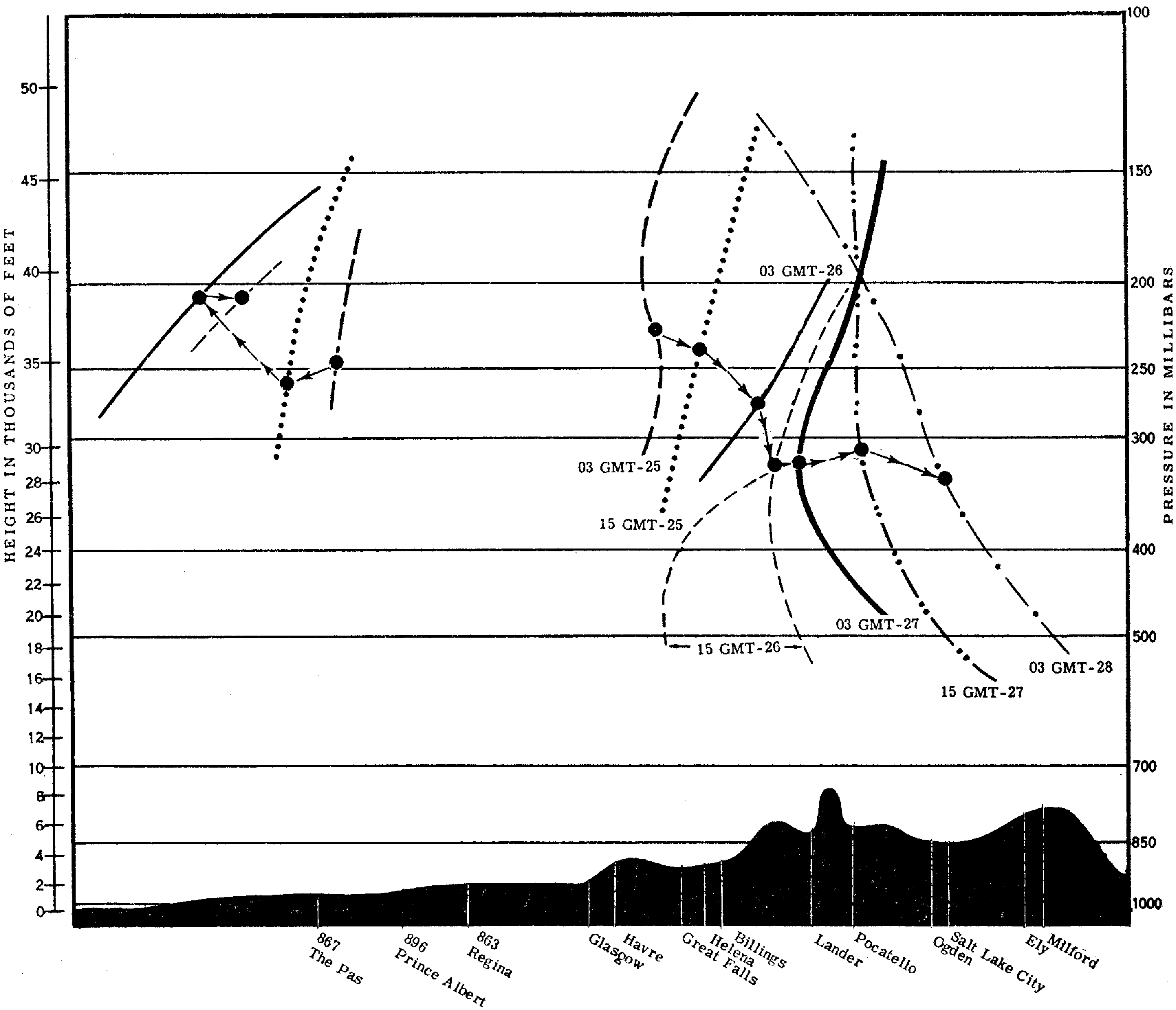

FIGURE 15.—Cross section for period November 25–28, 1954, showing slope of jet stream axis. Vertical extent of 80-knot isotach is indicated by length of axis. Large dot is jet core and arrows indicate movement of core. Note that the weak jet over Canada disappears on the 26th while the main jet over the United States increases in size and force with time. An interesting feature is that with warm ridge conditions (November 25), the axis of the jet slopes to the south with altitude while during cold trough conditions (November 28), the slope is reversed.

cold air in the troposphere the slope reversed, tilting to the north with altitude. As clearly shown by figure 15, the core of the jet moved to lower elevations as it moved southward. In this particular case, the implication is that as the vertical slope of a jet reverses itself going from a warm ridge to a cold trough, the horizontal axes of jets taken from constant pressure charts will cross somewhere near the inflection point of the upper flow.

The 1000–500-mb. thickness patterns are shown in figure 16. They show shrinkage (cooling) of over 1,000 ft. during this period for part of the northwestern United States. Thickness changes by layers for some of the stations along the cross section are tabulated in table 1. They show the cooling in the lower layers quite well for Great Falls, and Ogden, Utah, with compensation by a change (vertical motions in the upper stratosphere and/or advection of warmer or colder air into the layer) in the upper troposphere and the stratosphere. The most dramatic changes took place at Great Falls. There the thickness shrunk 1,190 ft. in the 1000–500-mb. layer and 950 ft. in the 500–300-mb. layer. This change can be accounted for by the complete cooling of the troposphere with the passage of a strong cold front. With only an 80-ft. rise at the 1000-mb. level, there must have been considerable change in thickness above 300 mb. to compensate for the strong cooling below 300 mb. With only an 880-ft. increase in thickness between the 300-mb. and 100-mb. levels, there is left a change of 1,180 ft. un-

TABLE 1.—*Changes in thickness (in tens of feet) of layers above selected stations for period 0300 GMT, November 25 to 0300 GMT, November 28, 1954. Change in height for 1000-mb. level*

Thickness layers / Stations	Churchill, Manitoba, Canada	Great Falls, Mont.	Ogden, Utah	Ely, Nev.	Las Vegas, Nev.	San Diego, Calif.
0-25 mb.			+540	+410 (0-50 mb.)		
25-50	+240 (0-100 mb.)	+1180 (0-100 mb.)	−140		+420 (0-200 mb.)	+60 (0-100 mb.)
50-100			+110	0		
100-200	−40	+740	+490	+230		+60
200-300	−230	+140	+290	−50	−30	−10
300-500	−30	−950	−210	−390* (300-1000 mb.)	+160	+20
500-1000	+120	−1190	−940		−420	−50
1000 mb.	−60	+80	−140	−200	−130	−80

*First transmission missing.

accounted for above 100 mb. An interesting feature, as shown in table 1, is the close relationship between the tendency of the 1000–500-mb. layer and that of the layer above 100 mb. In the case of Great Falls, these changes are practically identical, but with opposite sign. The same is true of Las Vegas, and San Diego, but deviates somewhat at Ogden, and Churchill. This relationship was pointed out by Showalter [7].

CONCLUSION

In the foregoing paper, the tropopause is treated as a physical surface embedded in and moving with the atmosphere. The variations in the tropopause and changes in other related meteorological parameters are noted as they move through a vertical cross section. It is apparent that the use of cross sections is necessary for a detailed analysis of the many minor tropopause leaves. Thus the current practice of tropopause analysis using only a horizontal chart, is at best a crude solution regardless of the care taken in such analysis.

ACKNOWLEDGMENTS

The authors are indebted to the staff of WBAN Analysis Center for their comments and criticisms.

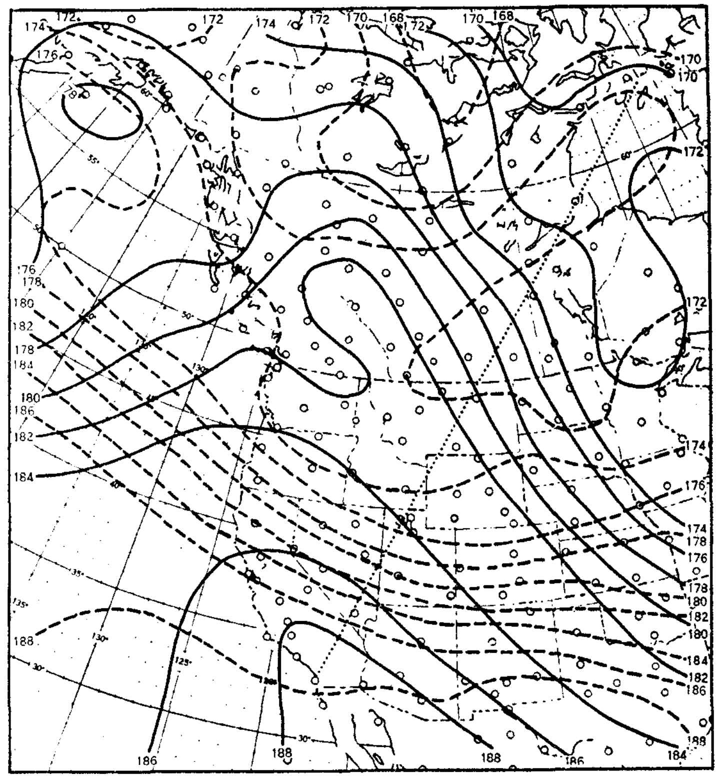

FIGURE 16.—1000-500-mb. thickness for 0300 GMT, November 25 (solid lines) and for 0300 GMT, November 28, 1954 (dashed lines). Note the strong changes in the Idaho-Montana region.

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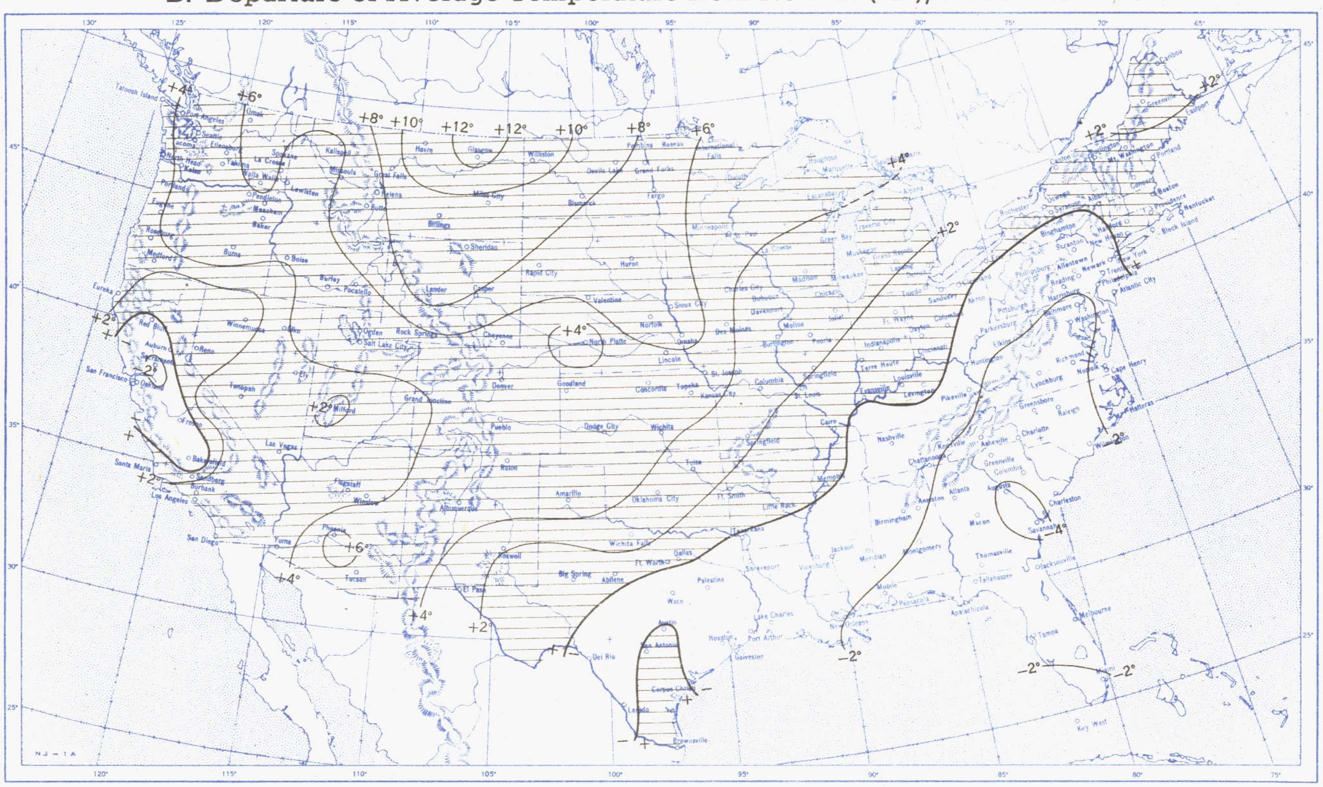
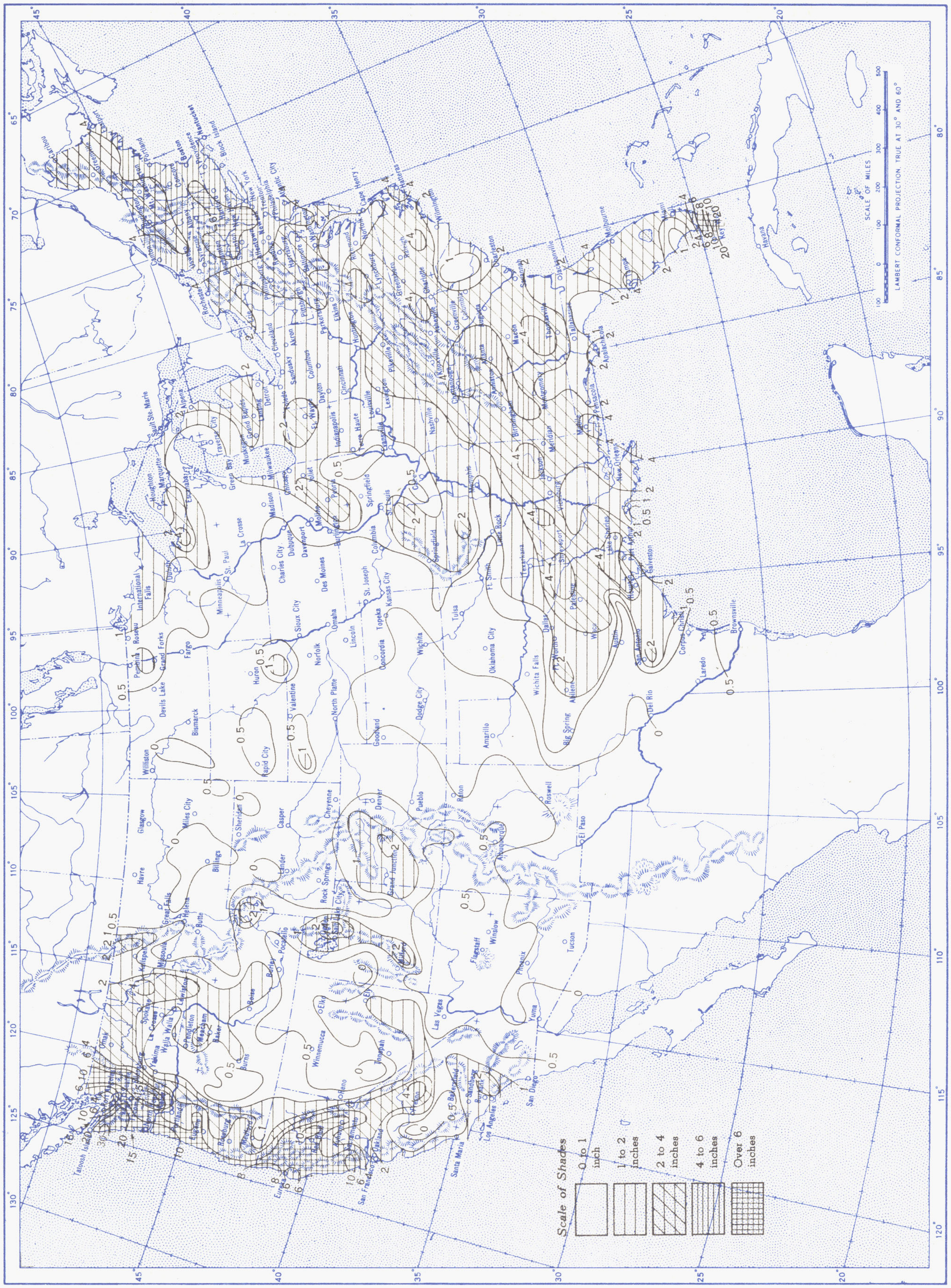
Chart I. A. Average Temperature (°F.) at Surface, November 1954.

B. Departure of Average Temperature from Normal (°F.), November 1954.



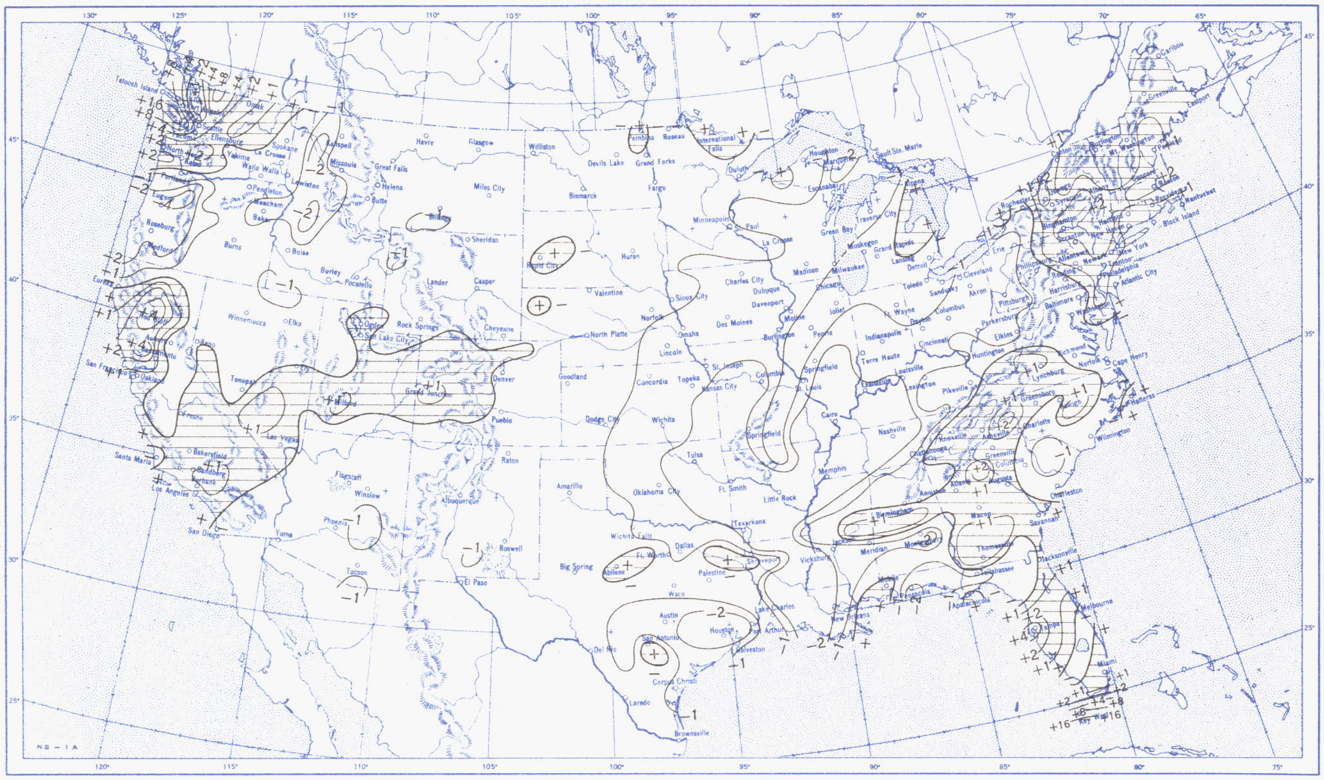
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), November 1954.



Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), November 1954.



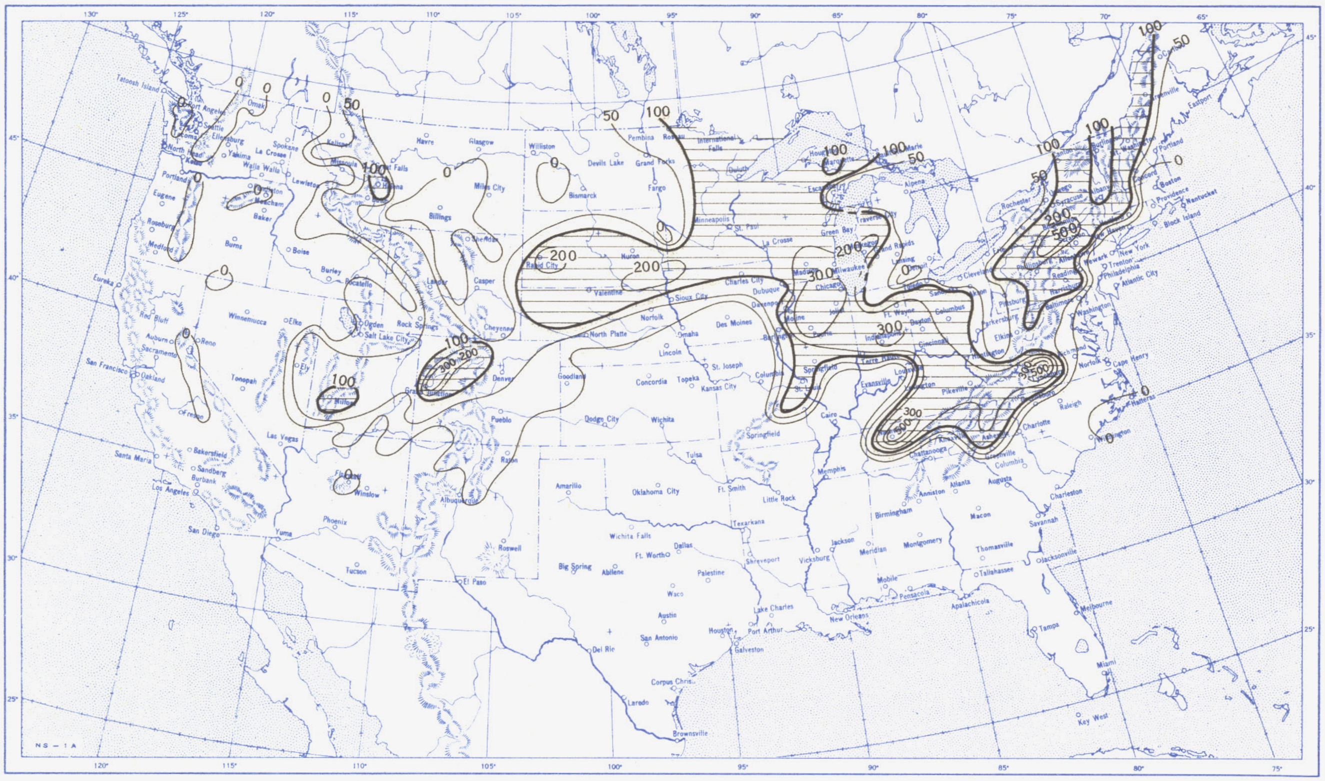
B. Percentage of Normal Precipitation, November 1954.

Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), November 1954.

This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

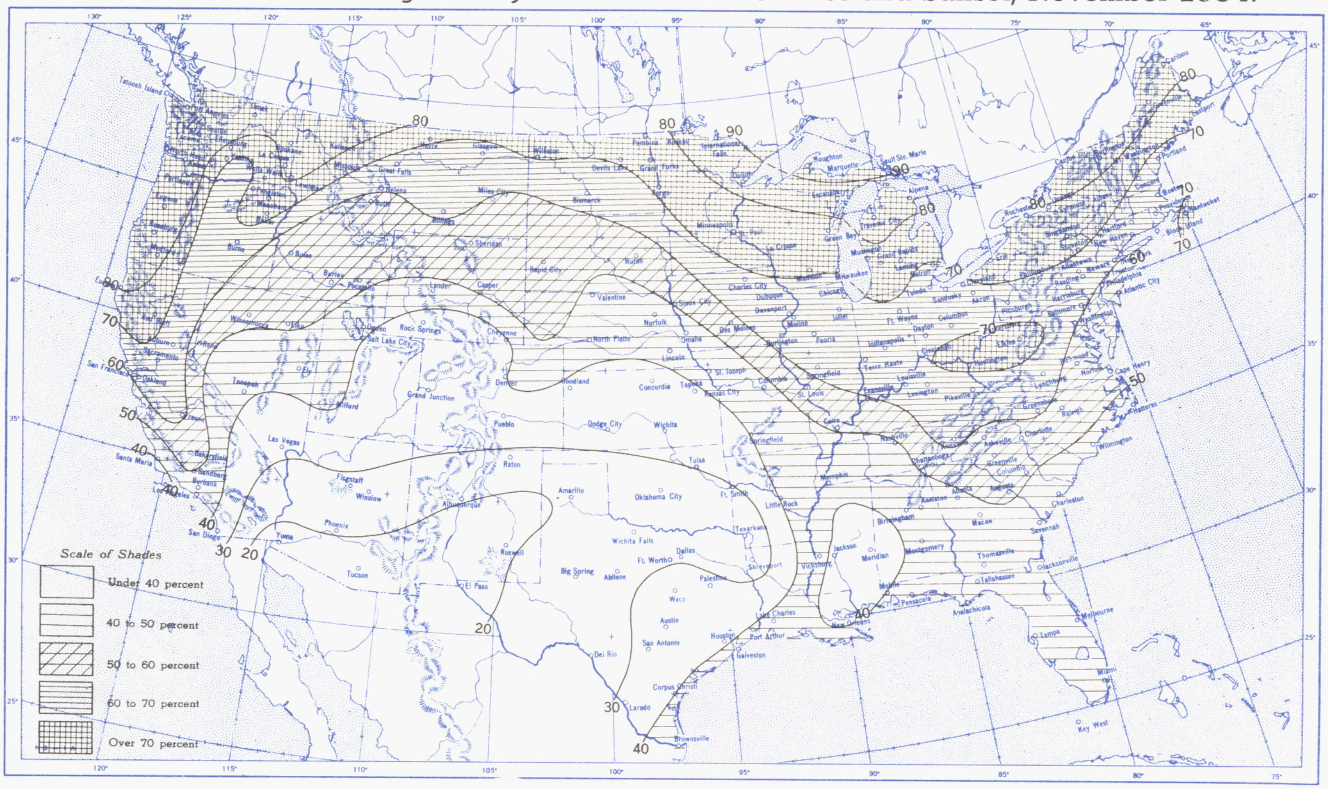
Chart V. A. Percentage of Normal Snowfall, November 1954.



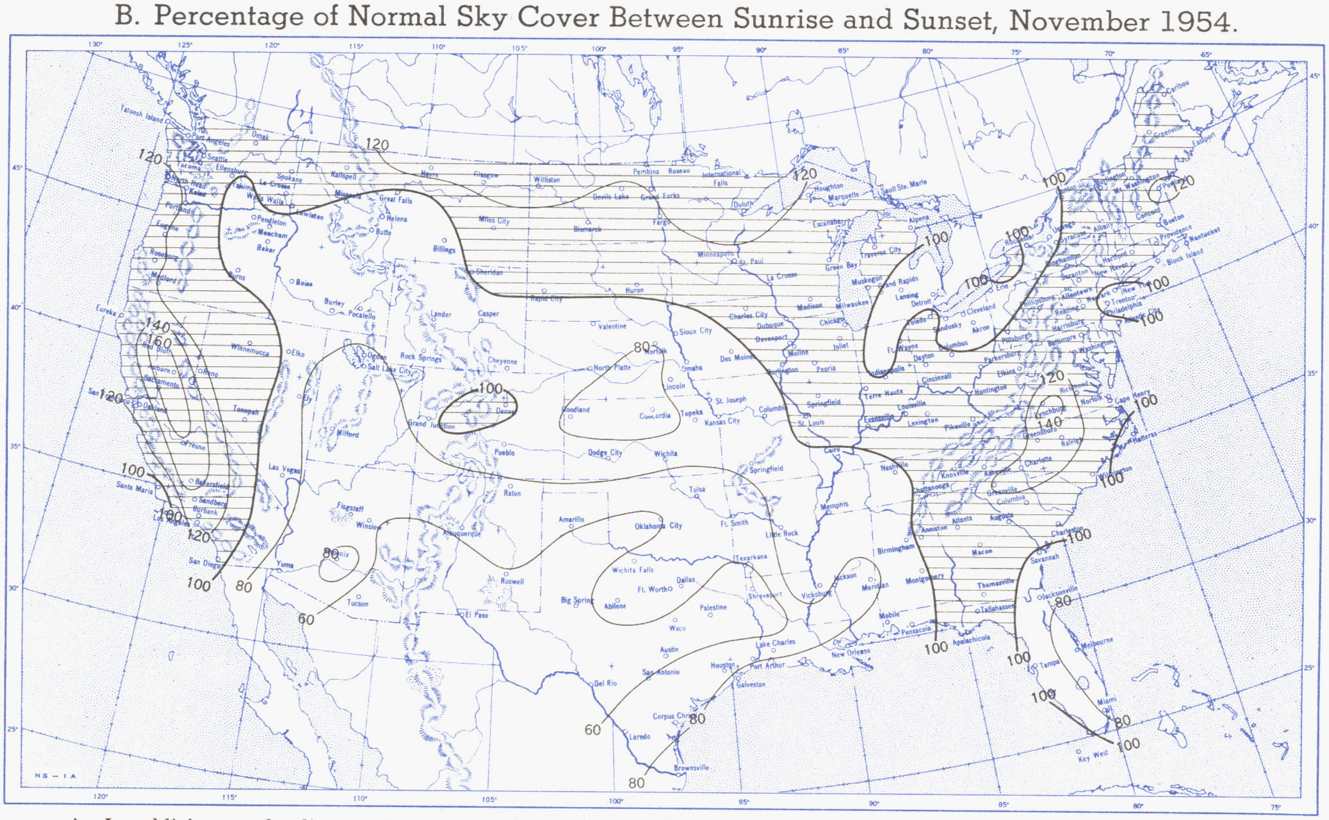
B. Depth of Snow on Ground (Inches).

A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record. B. Shows depth currently on ground at 7:30 a.m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, November 1954.

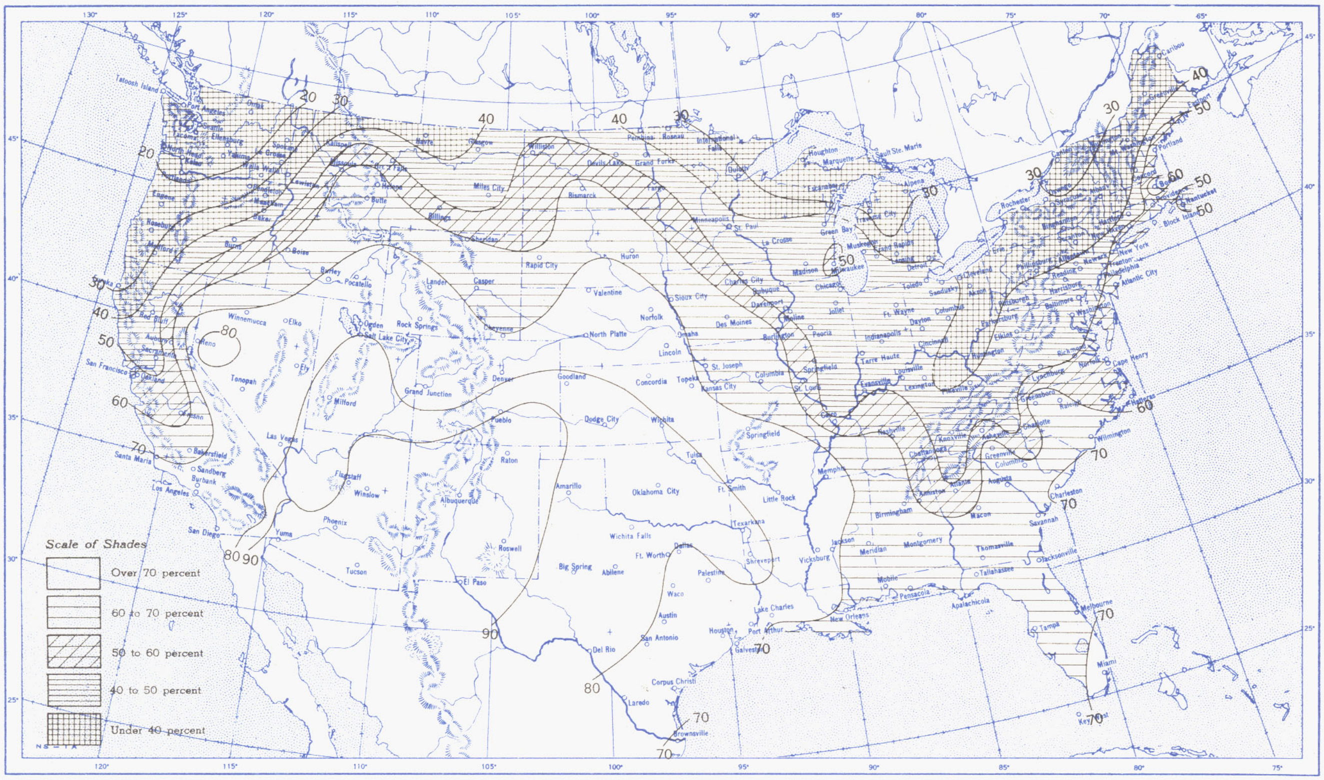


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, November 1954.

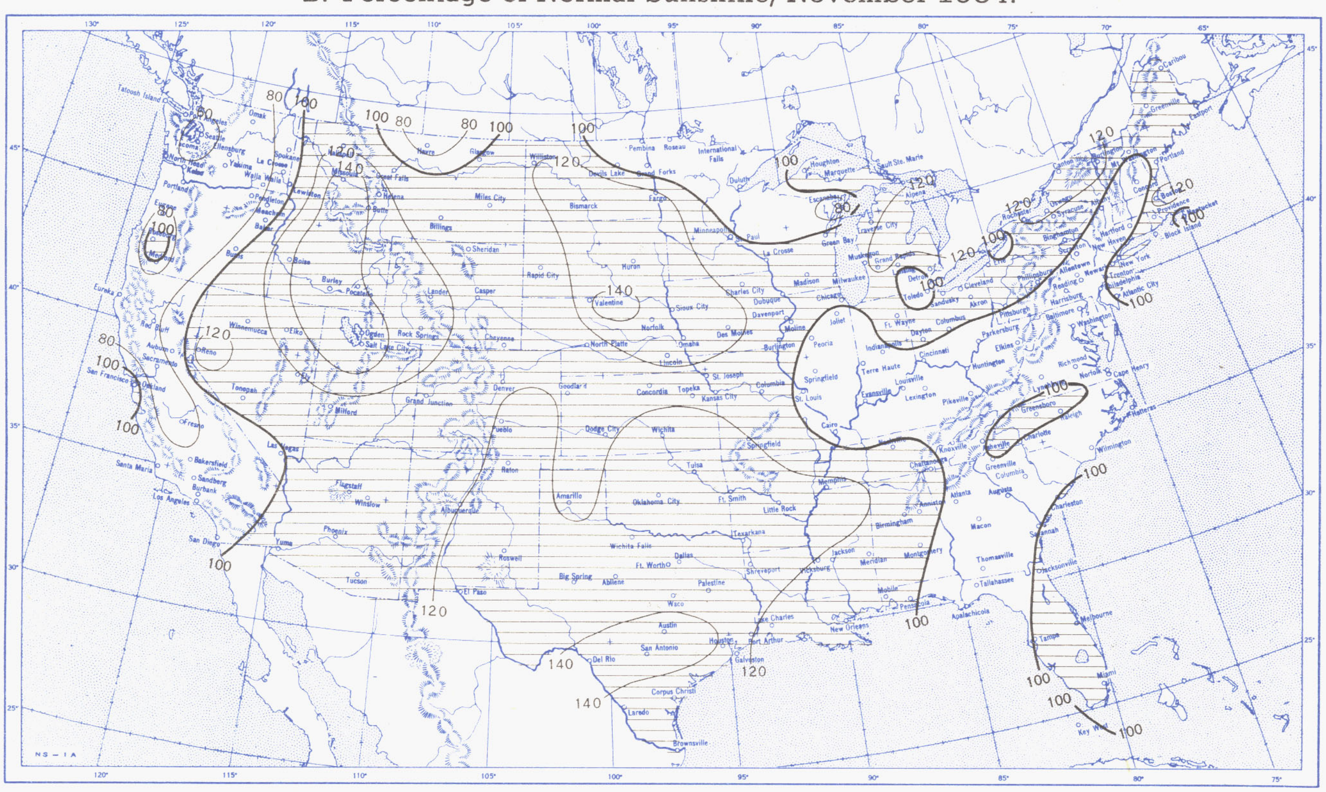


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, November 1954.



B. Percentage of Normal Sunshine, November 1954.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, November 1954. Inset: Percentage of Normal Average Daily Solar Radiation, November 1954.

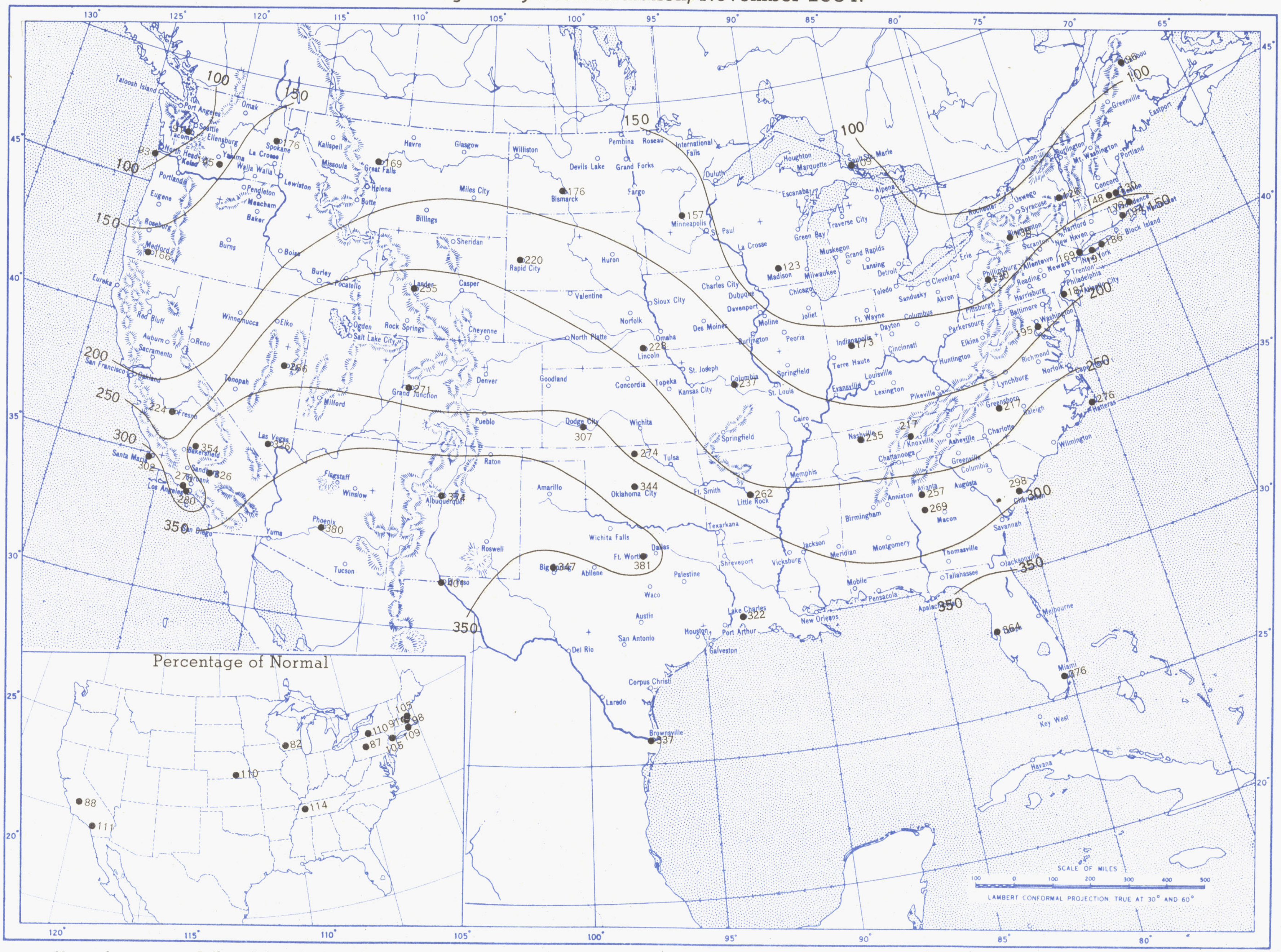
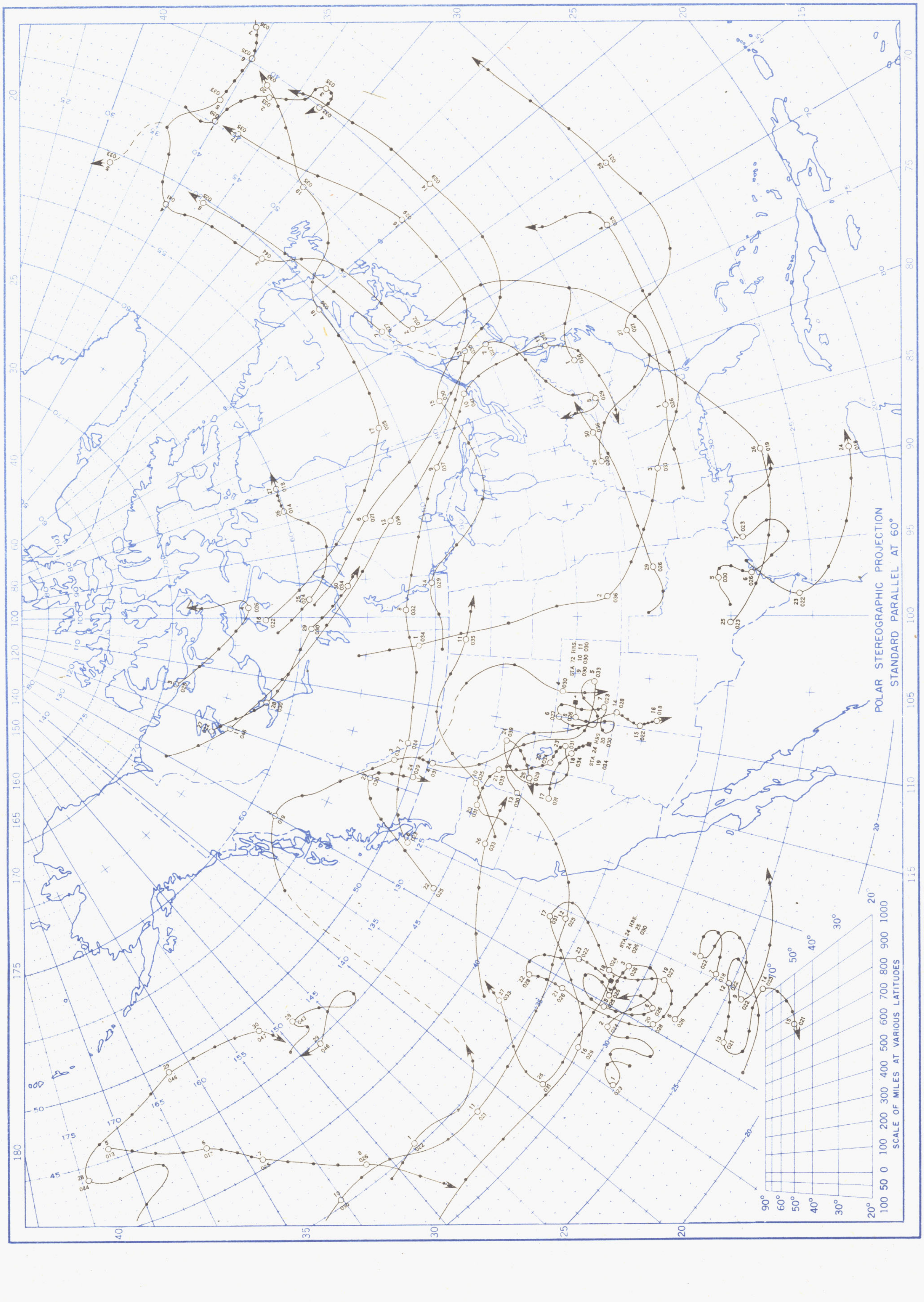


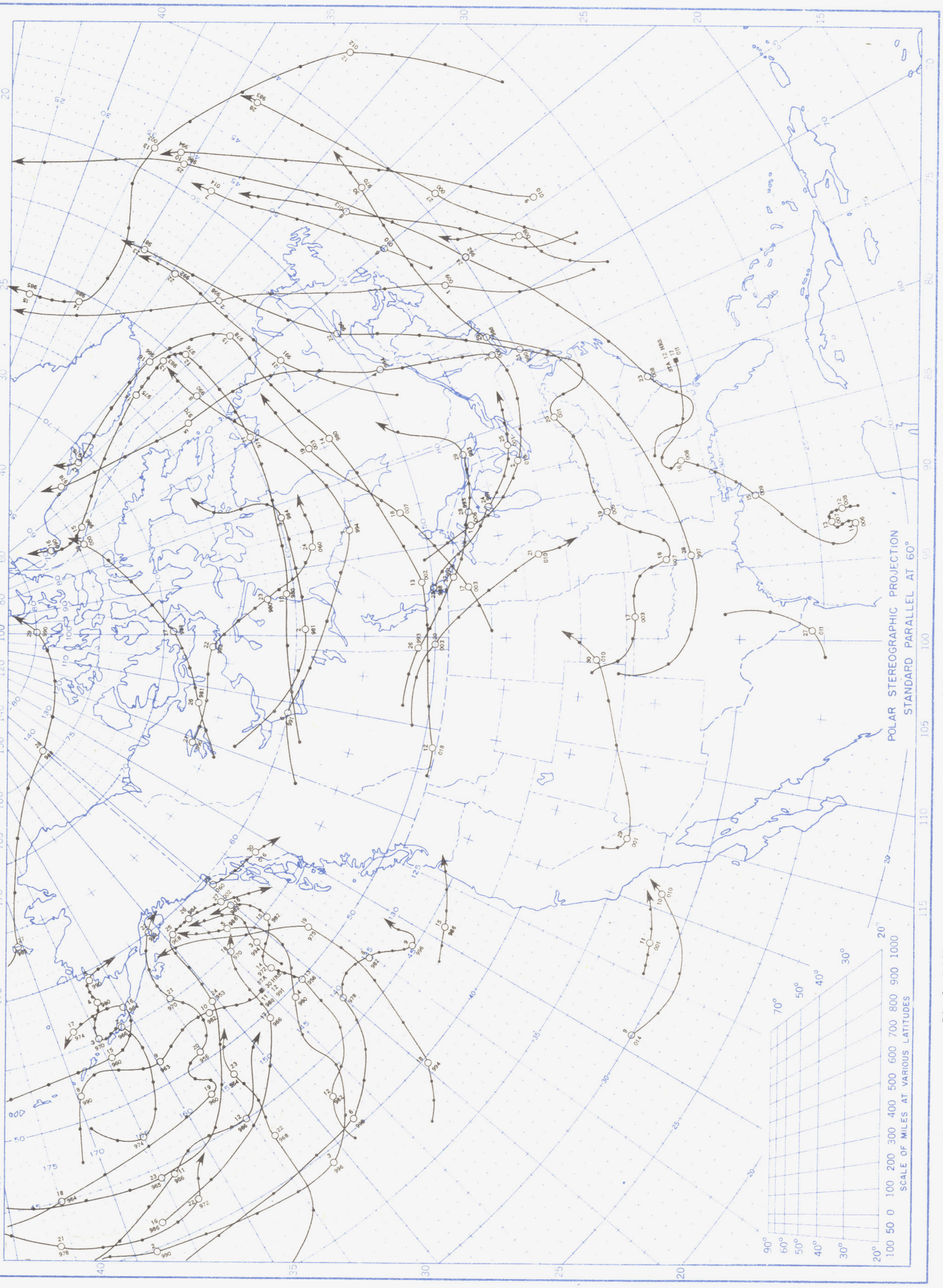
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, November 1954.



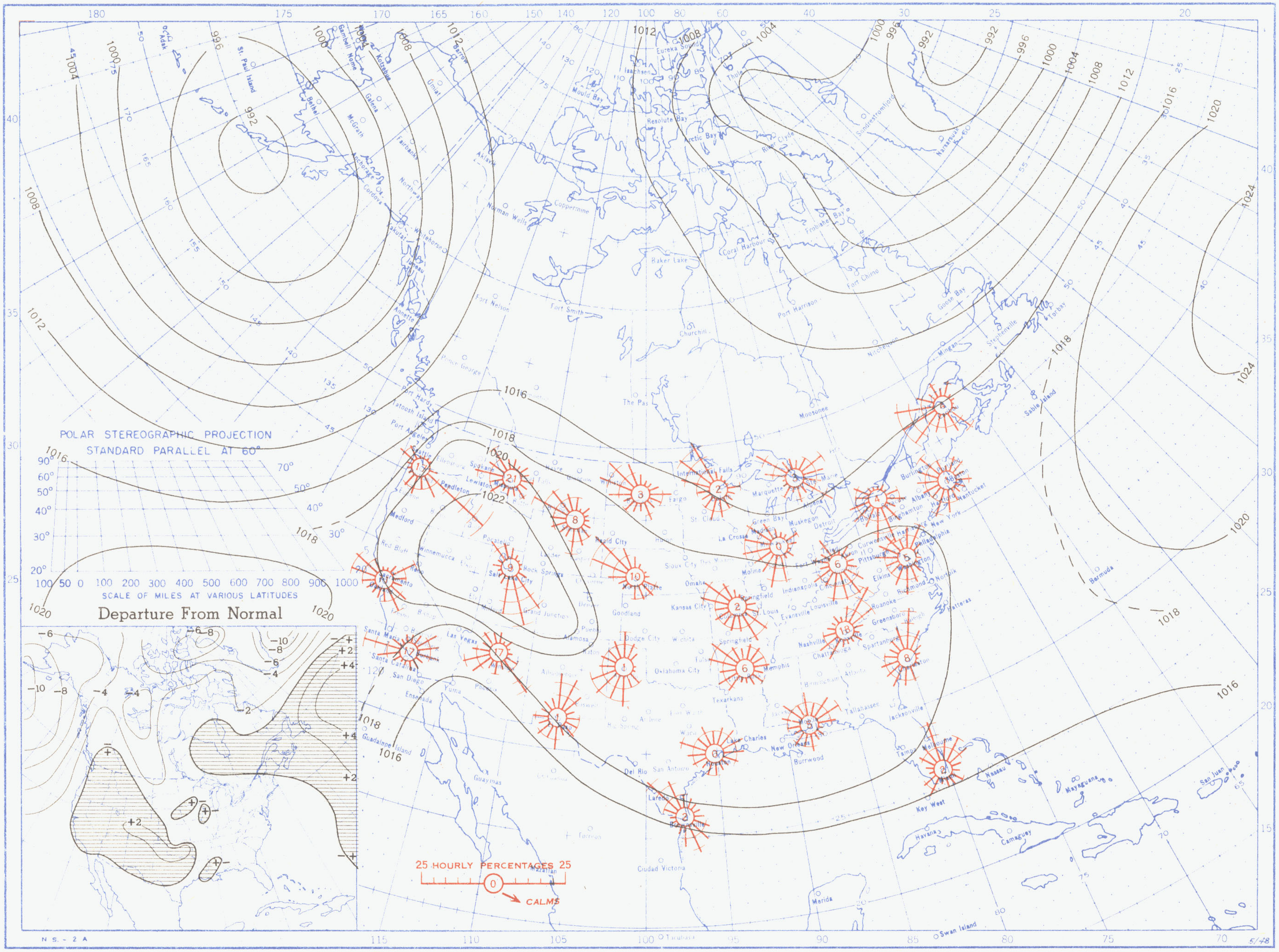
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, November 1954.



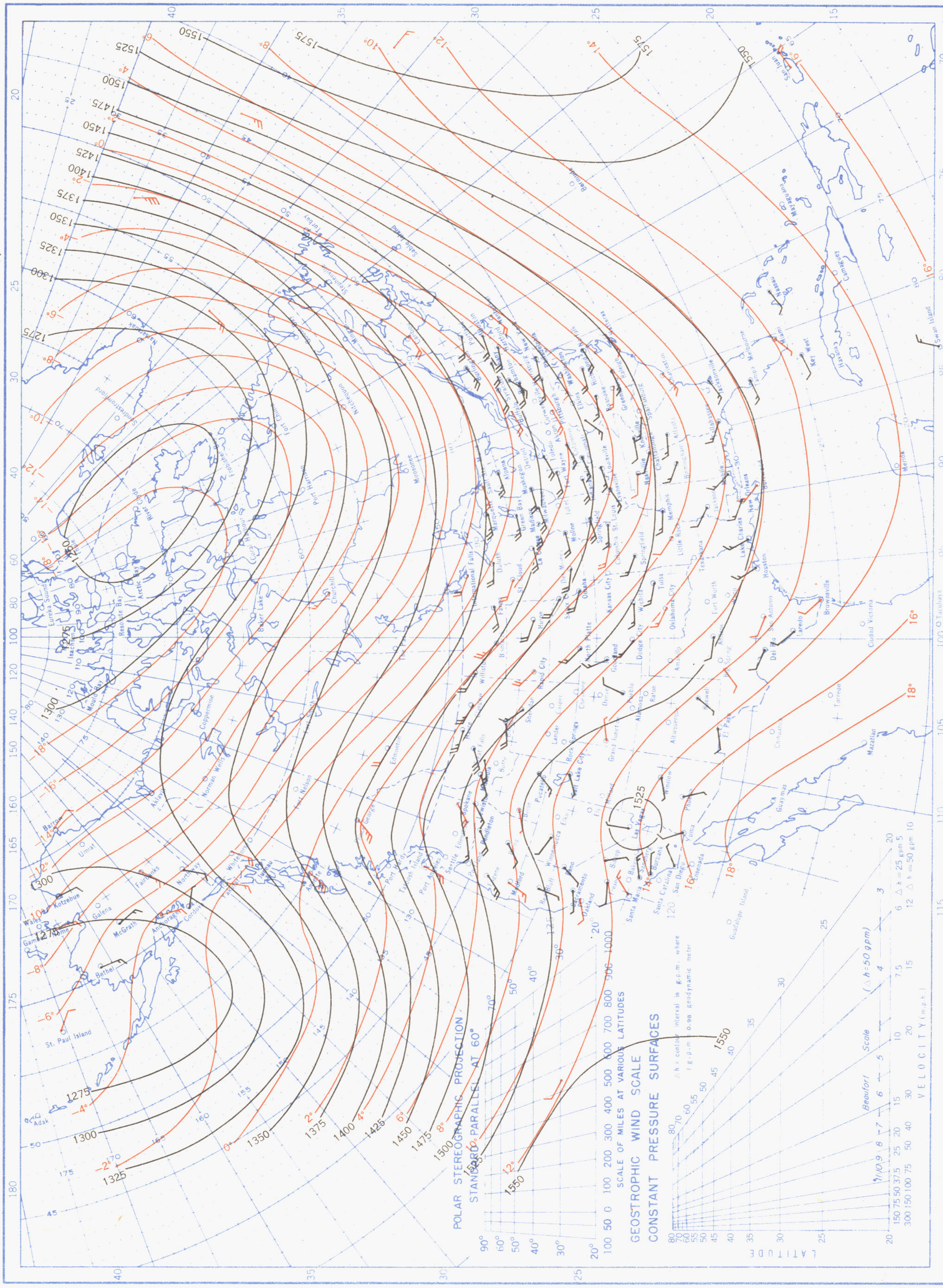
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, November 1954. Inset: Departure of Average Pressure (mb.) from Normal, November 1954.



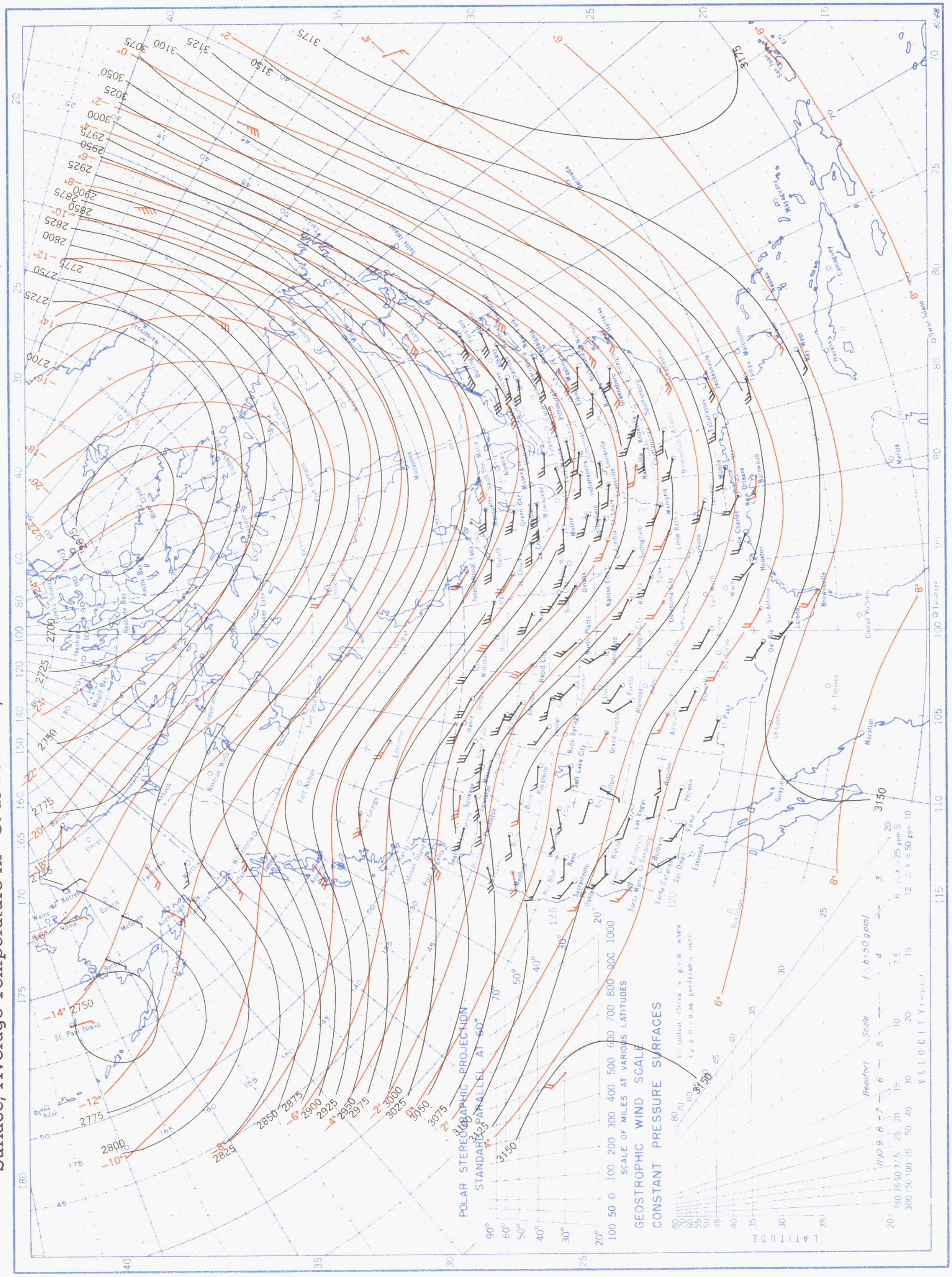
Average sea level pressures are obtained from the averages of the 7:30 a.m. and 7:30 p.m. E.S.T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), November 1954.



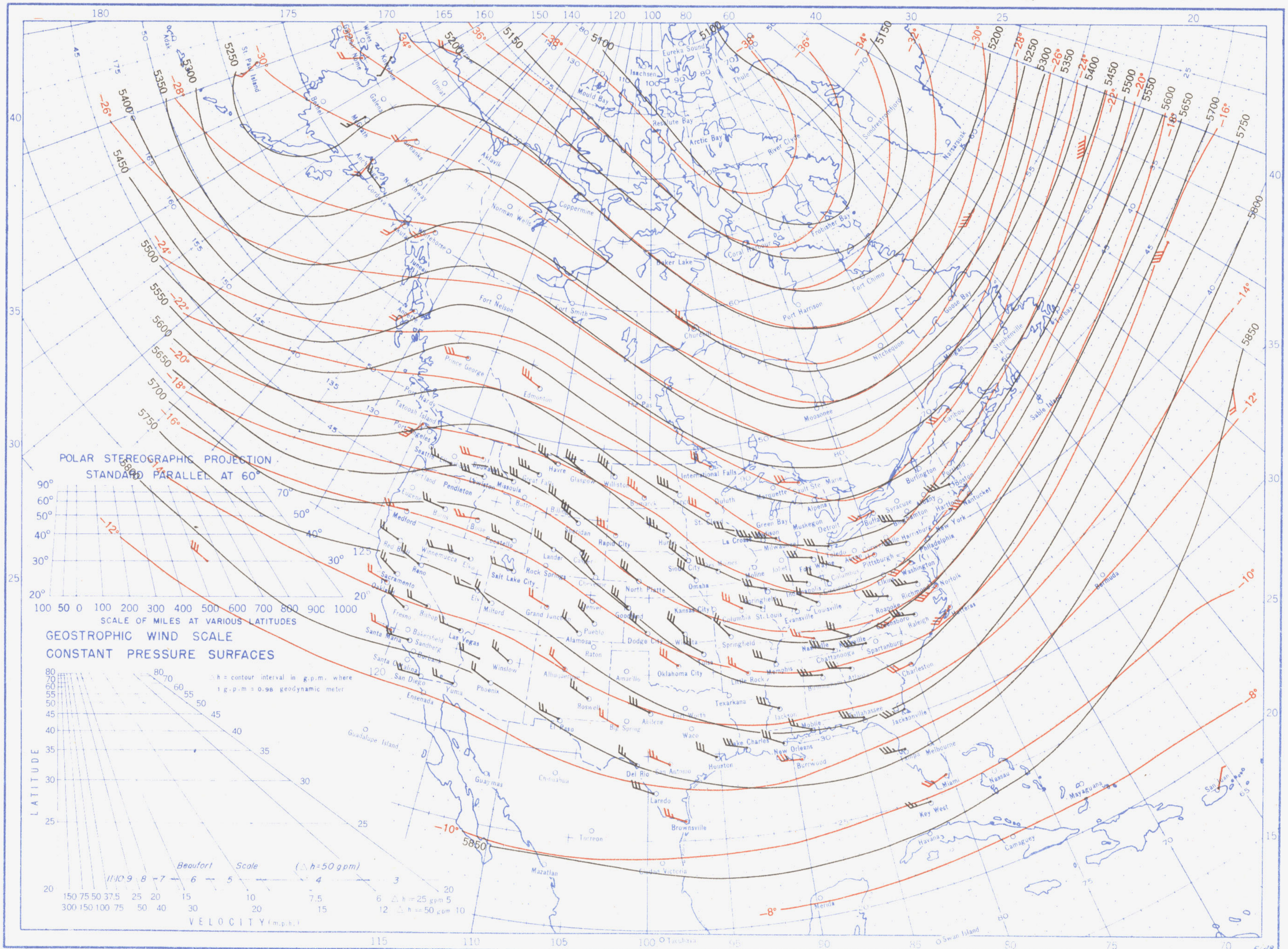
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), November 1954.



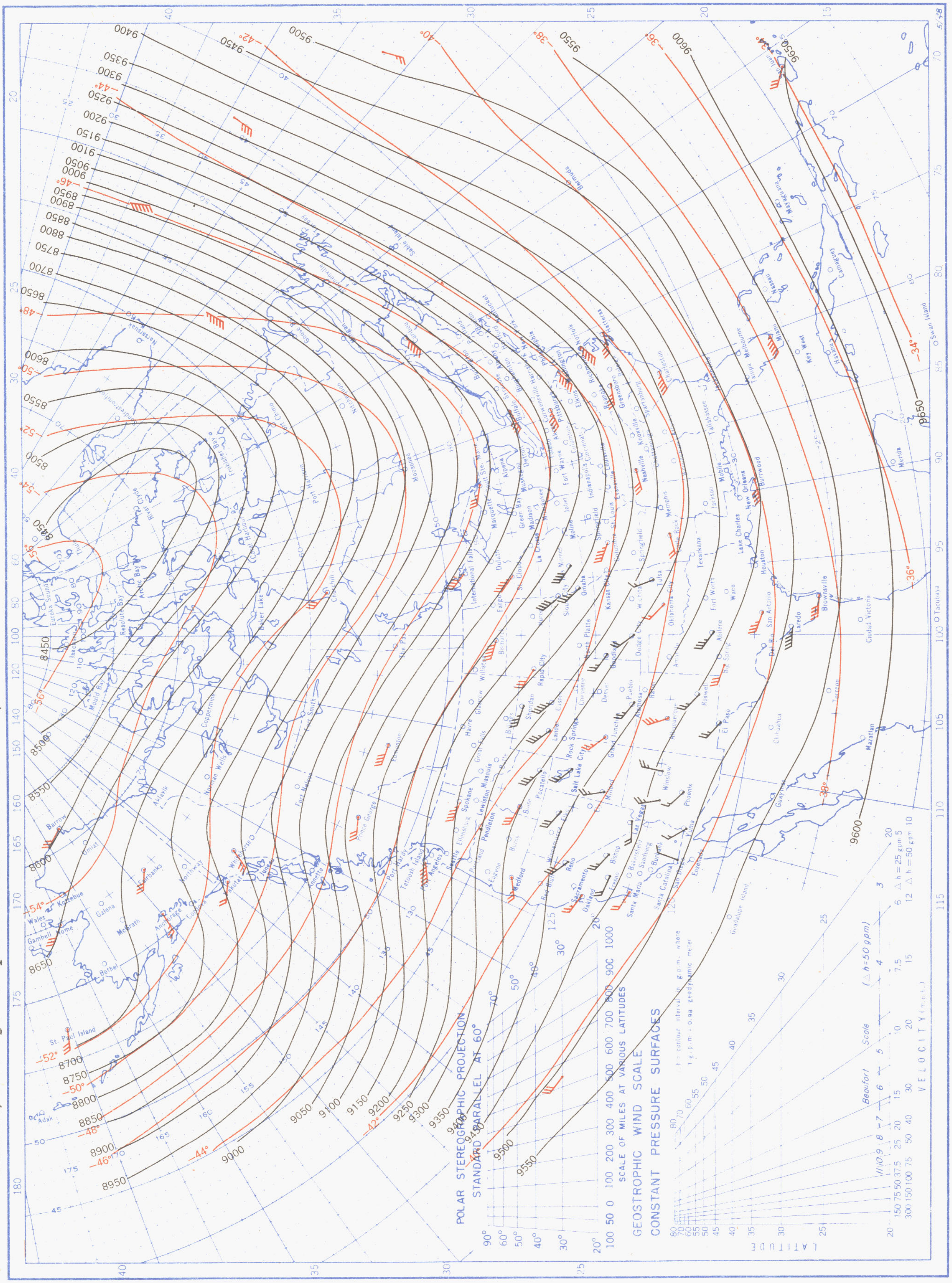
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), November 1954.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), November 1954.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.